A TEXTBOOK

ON

MINING ENGINEERING

INTERNATIONAL CORRESPONDENCE SCHOOLS

SCRANTON, PA.

ECONOMIC GEOLOGY OF COAL

PROSPECTING FOR COAL AND LOCATION OF OPENINGS

SHAFTS, SLOPES, AND DRIFTS

METHODS OF WORKING COAL MINES

MECHANICS

STEAM AND STEAM-BOILERS

STEAM-ENGINES

AIR AND AIR COMPRESSION

HYDROMECHANICS AND PUMPING

WITH PRACTICAL QUESTIONS AND EXAMPLES

1907

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CONTENTS.

INDEX.

NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Atom, 16 1" means that atom will be found on page 1 of section 16.

C.

T.

ECONOMIC GEOLOGY OF COAL.

SURFACE AND STRUCTURAL GEOLOGY.

INTRODUCTION.

1278. Economic Geology is that department of natural science which treats of the structure of the earth's crust in its relation to its mineral products.

1279. The Economic Geology of Coal treats of the deposition, formation, and occurrence of coal, the shape and character of the coal deposits and their accompanying strata, and the nature and the history of the adjacent formations, as far as it will assist in mining.

It is as important that practical men should know what strata do *not* contain coal, as to know what strata do; therefore, we will briefly describe the formations below and above the coal measures.

1280. Dynamic Geology treats of the natural forces that operate in changing and modifying the structure of the earth's surface. These forces are known as *atmospheric*, *aqueous*, *igneous*, and *organic*.

1281. Atmospheric action disintegrates rocks and forms soil.

1282. Aqueous action, or the action of water, is either mechanical or chemical. Rivers, oceans, and ice exert mechanical force, and mineral waters cause chemical changes.

1283. Igneous action, or the action of heat, aids in the elevating of and the depressing of the sea bottom, and in the production of the inequalities of the earth's surface. All crust motion is due to the interior heat of the earth.

1284. Organic action was the cause of vegetable accumulations, forming coal and bitumen, and of animal accumulations, forming limestones.

1285. In Fig. 352 is shown an ideal section of the earth's crust. The references are as follows:

A, Recent Formations; *B*, Quaternary Formations;

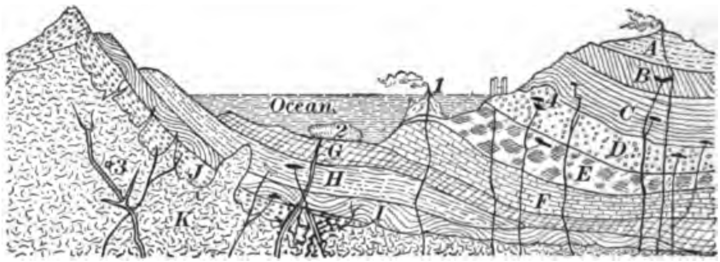

FIG. 352.

C, Tertiary; *D*, Mesozoic; *E*, Carboniferous; *F*, Devonian; *G*, Silurian; *H*, Cambrian; *I*, Pre-Cambrian; *J*, Laurentian; *K*, Molten and Igneous Rocks. *1*, Coral Reef; *2* and *3*, Granite Intrusion; *4*, Laccolite.

THE EARTH'S CRUST.

1286. The outer surface of the earth is a cool crust covering and enclosing incandescent matter in the interior. This crust consists of a solid structure with an irregular surface, consisting of mountains, plains, and valleys. The deepest depressions are filled with water and form the oceans and lakes.

1287. The mean temperature of the whole earth's surface is about 58° Fahrenheit, the northern hemisphere being about 60° Fahr., and the southern hemisphere 56° Fahr. There is in every locality a daily and an annual variation of temperature. The depth at which there is *no daily variation* is but a foot or two below the surface, but the depth of *invariable* temperature in temperate climates is about 60 or 70 feet. At the equator the depth of *invariable* temperature is only one or two feet from the surface. In high latitudes, approaching the poles, the depth of invariable temperature

increases and probably exceeds 100 feet. Beneath the depth of invariable temperature the temperature of the rocks increases for all depths to which it has been penetrated. This rate of increase, however, is not uniform in all localities. It is sometimes faster in one locality than in another, all depending on the conductivity of the rock penetrated. Observation has given us the fact of increase, but no law. The following formula gives results conformable with the general results of observations:

$$T = 50.68 + \frac{D - 19.68}{67.2}, \qquad \textbf{(83.)}$$

where $T =$ temperature in degrees Fahrenheit;
$D =$ depth penetrated.

The mean density, or specific gravity, of the earth, as a whole, has been determined by several different methods at about 5.6, considering the density of water as 1. The density of the materials forming the earth's surface, leaving out water, is not more than 2.5. It is evident, therefore, that the density of the central portion must be more than 5.6.

STRATIFIED ROCKS.

1288. Stratified, or sedimentary, rocks consist, for the most part, of sand and mud thrown down originally either at the mouths of rivers along the sea-shore or in lakes. The materials vary greatly in degrees of fineness. The coarsest is a mass of rounded pebbles formed along a rocky shore. When these shingle pebbles are cemented together by a fine material they form conglomerate. Sand beds are composed of minute, loose, angular stones, accumulated before their corners were rounded. Gravel consists of loose rounded stones, or pebbles. Breccia consists of angular stones consolidated.

Stratified rocks are of three kinds, *arenaceous*, *argillaceous*, and *calcareous*, and a fourth, *organic*, may reasonably be added.

1289. **Arenaceous** rocks, in their incoherent state, are sand, gravel, shingle, rubble, etc., and in their

compacted state, are sandstones, gritstone, conglomerates, and breccia.

1290. Argillaceous rocks, in their incoherent state, are muds and clays. When partly consolidated and finely laminated, these muds and clays form shales. When fully consolidated and laminated, they form slates.

1291. Calcareous rocks are chalk, limestone, and marble. They are seldom in an incoherent state, except as chalk. Limestones were formed by deposits in lakes or seas, and are the powdered remains of shells, corals, fish, sponges, etc., consolidated in a coherent mass. They are, therefore, organic sediment.

Calcareous rocks deposited by chemical action are due to the fact that water can keep carbonate of lime dissolved only as long as it contains carbonic acid dissolved in it as well. When such water emerges into the air it loses some of its carbonic acid, and is unable to retain the lime in solution, which is then deposited.

Nearly all the limestones, all the coal, and some silicious beds are composed of stony relics of either plant or animal life.

1292. The calcareous materials, or the constituents of lime, come mostly from:

1. Shells of mollusks, or animals of the oyster, clam, or mussel type.

2. Corals, or the secretions of marine animals of a lower grade than vertebrates.

3. Crinoids, a family of marine animals of the nature of star fish.

4. Calcareous shells of rhizopods, corallines, coccoliths, and rhabdoliths, marine animals of the lowest order, known as Foraminifera.

When the above animal life in the sea was profuse, limestones were formed.

The rhizopods, or the organic remains of shells, or corals, or crinoids, probably made the limestones of the Paleozoic

era. If rhizopods enter largely into the formation, the limestones were probably accumulated in deep water.

1293. The conditions necessary for the growth of reef-building corals are: the temperature must be mostly that of the Torrid Zone; the depth of water must not exceed 100 feet; the water must be salt and clear, and the corals must be freely exposed to waves. Since corals can not grow in waters more than 100 feet deep, it is evident that subsidence keeps pace with the growth of the corals; otherwise, it is impossible to account for the enormous thickness of coral reefs. However, there is no evidence of subsidence on the coast or keys of Florida, and it is therefore supposed that the Florida reefs were formed partly by organic sediment brought by the Gulf Stream from other coral banks in the Caribbean Sea, but mostly built up by the accumulation of shells of successive generations of deep-sea animals, the Gulf Stream contributing only the conditions necessary to rapid growth, warmth, and food.

1294. Shallow water deposits of molluscous shells are made principally by mollusks living in great numbers near the shore, and on submarine banks. They left their shells generation after generation, sometimes forming pure shell deposits, and sometimes shells mingled with sediments due to other agencies.

1295. Over nearly all the bottoms of deep seas, at depths at which sedimentary deposits are impossible, we find a deposit of carbonate of lime, shells of foraminifers, and coccospheres of microscopic plants. Chemical and microscopic examinations of these deposits lead to the belief that chalk was formed in this manner.

The formation of limestones from shells or crinoidal remains is similar to that from corals, the waves wearing them, or part of them, to mud, when consolidation takes place. The rate of formation of limestones from shells is slower than that of coral or crinoidal limestone, since the calcareous secretions of mollusks contain, proportionately, much less carbonate of lime.

1296. These arenaceous, argillaceous, calcareous, and organic materials, or sands, clays, lime, and vegetable matter, may gradually combine with each other to form the argillaceous sandstones, calcareous sandstones, calcareous shales, marl, and organic shales.

There is abundant and conclusive evidence that stratified rocks are more or less consolidated sediments. Beds of clay and mud, and sand, may be traced, by almost insensible gradation, into shale and sandstone.

The cementing material, such as carbonate of lime, silica, or oxide of iron, present in percolating water, accounts for the consolidation of sediments into rocks.

In many cases rocks have been deposited with extreme slowness. In proof of this statement, shales are found the lamination of which is beautifully distinct, although each lamina is no thicker than cardboard. Each lamina was separately formed by alternating conditions, such as the rising and falling of tides or the flood and fall of rivers.

1297. Stratified rock must have been originally nearly horizontal, as such a position would naturally be assumed by all sediment in obedience to the law of gravity. It may, therefore, be assumed that highly inclined or folded strata have been changed since first deposited and consolidated. The planes separating strata were not originally all horizontal, nor was each stratum always of uniform thickness. Each stratum, when deposited, should be regarded as a widely expanded cake, thickest in the middle and thinning out at the edges, and interlapping there with similar cakes. In Fig. 353, *c* is sandstone and conglomerate, and *b* is limestone.

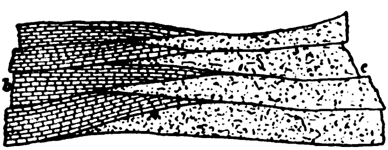

FIG. 353.

In fine materials, strata assume the form of extensive thin sheets, while coarse materials thin out more rapidly, and are more local.

The oblique lamination is a most important exception to the law of horizontality, and is considered a phenomenon

Oblique lamination is due to rapidly shifting currents bearing lots of coarse materials, or to chafing of waves on an exposed beach. Fig. 354 is an example.

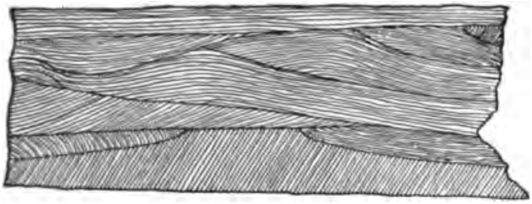

FIG. 354.

1298. Elevated, Inclined, and Folded Strata.—Assuming that stratified rocks were deposited as sediment at the bottom of water in a nearly horizontal position, it is evident that some great force has been at work changing the position of the rocks composing the earth's crust. These rocks are found in the vicinity of the oceans, but more often in the interior of the continents, high up on the mountains; sometimes they are horizontal, though high up; sometimes the strata at this elevation are still soft, but, as a rule, of a stony nature. In the mountain regions the strata are tilted at all angles, folded, contorted, overturned, broken, and slipped, so that it is difficult, in many instances, to determine their original order of superposition.

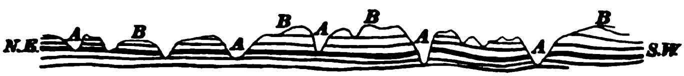

FIG. 355.

The outlying coal fields of Western Pennsylvania show clearly how strata, high up in the mountains, are found in a nearly horizontal position. (See Fig. 355.)

1299. Dip and Strike.—The dip of strata is their inclination from a horizontal plane. Fig. 356 shows strata dipping southward about 45°. The angle of dip is measured by a clinometer, and the direction of dip by a compass. The two instruments are often conveniently combined in one.

The strike of strata is the line of intersection of the strata with a horizontal plane. It is always at right angles to the

dip. In Fig. 356, the line *b c* shows the thickness of the

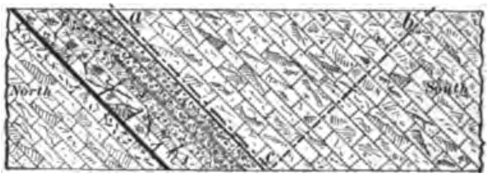

FIG. 356.

strata. The thickness $b\ c =$ distance $a\ b \times \sin 45°$, provided the strata are free from troubles.

With a disturbance of the strata, as shown in Fig. 357, no rule can be given with which to calculate their thickness. If the dip is known, the strike is also known; but if the

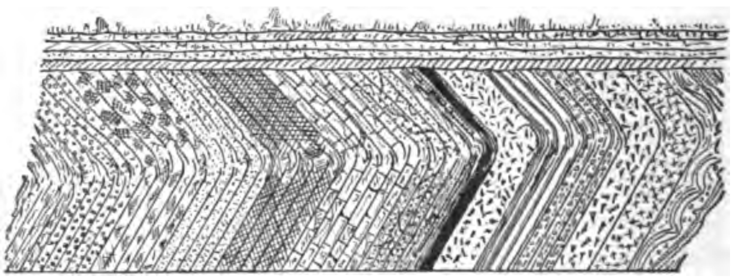

FIG. 357.

strike is given, the dip can not be known from it, because the dip may be inclined to either side of the strike. For example, if the strike is due east and west, the dip may be either north or south.

1300. Anticline, Syncline, Monocline, Pericline, Escarpment, and Outcrop.—When strata dip in opposite directions from a ridge, or line of elevation, the ridge so formed is called an anticline, or saddle-back, and the line of elevation is termed the **anticlinal axis,** as at *a*, Fig. 358. When strata dip towards a common line of depression, as at *b*, the axis is said to be **synclinal,** and the depression so made is spoken of as a **syncline trough,** or **basin.**

Synclinals may be found without anticlinals, and anticlinals may be found without synclinals. Anticlinals may

be found directly over synclinals, and there may be a number of anticlinals and synclinals within one great synclinal.

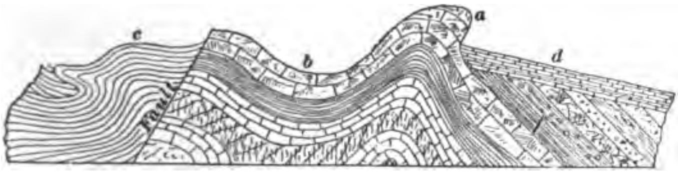

FIG. 358.

Fig. 359 shows a section across the entire region of the anthracite coal field of Pennsylvania, which is an excellent example of these conditions. Each separate division, or basin, is a syncline within a larger syncline, and each division is again subdivided into still smaller synclines, or basins.

Anticlinals do not always form the higher ground, as might at first be supposed, but frequently form the bottoms of the valleys, while the synclinals are found in the hills.

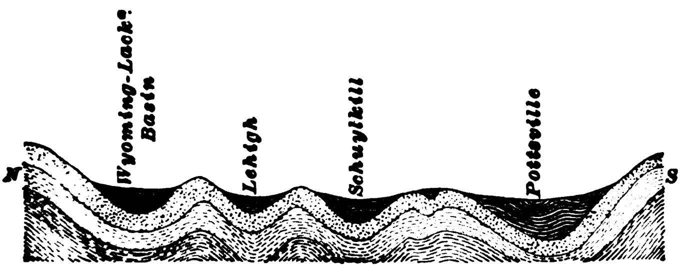

FIG. 359.

The Pittsburg region is also traversed by a system of low or very flat anticlines and intermediate synclines, whose axes bear in the same general direction as the anthracite basins and saddles do, namely, N E and S W. The Connellsville coal field is the most easterly of the synclinal basins in the Pittsburg region.

1301. The strata are said to be **monoclinal** when, though lying at different angles, they all dip in the same direction, as at *a b*, Fig. 360; **periclinal**, when they dip in every direction from a common center like a cone.

When strata terminate abruptly in a bold, bluff edge, they form an **escarpment.**

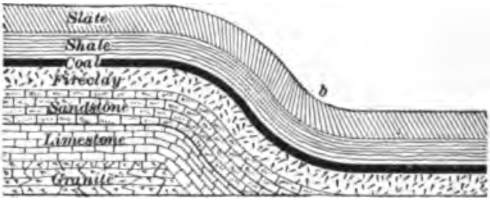

FIG. 360.

When any strata can be seen at the surface, the exposure is called the **outcrop.**

1302. Conformity and Unconformity.—When strata lie upon each other in parallel order, as at *d*, Fig. 358, they are termed **conformable;** but when one set inclines upon another at a different angle, they are termed **unconformable.** (See *d* and *f*, Fig. 358.) When strata are bent and twisted, they are termed contorted. (See *c*, Fig. 358.)

1303. Geological Formation.—A group of strata conformable throughout and containing similar fossils or organic remains, and separated from other conformable groups by a line of unconformable rocks, is called a **geological formation.**

1304. Concretions.—There is a chemical process common in stratified rocks which results in the formation of **nodules,** or **concretions.** For example, the flint nodules in chalk are due to the presence, among the chalk, of small shells, sponges, etc., which were chemically acted upon by percolating water and formed into flint nodules.

In many stratified rocks, nodules of various kinds are found, scattered through the mass, or in layers, parallel to the planes of stratification, or in groups, sometimes so thickly deposited as to form local patches of stone or gravel beds. The structure, like slaty cleavage, is the result of internal changes subsequent to the sedimentation, for the planes of stratification frequently pass through the nodules. The clay iron-stone nodules of the coal strata are familiar illustrations of this structure.

These nodules, or concretions, take quite a variety of shapes and are of all sizes up to many tons in weight. They frequently have a network of cracks inside, which may be

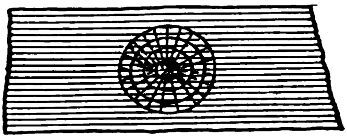

FIG. 361.

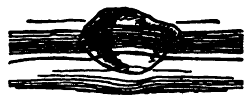

FIG. 362.

filled with different minerals. In coal beds, they are the nigger-heads and sulphur balls. In shales, there may be nodules of siderite or clay iron-stone. In limestone, the nodules are always silica. In sandstone strata, the nodules are commonly carbonate of lime or oxide of iron—lime or iron balls (Figs. 361 and 362).

The bending up and down of strata, quite locally, is sometimes due to the presence of large concretions, which, in process of formation, seem to have swelled the strata or pushed them away. (See Fig. 363.)

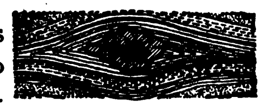

FIG. 363.

During the formation of coal, stumps and logs were floated off into lakes, to sink and become buried in the accumulating vegetable débris, or in deposits of detritus, and some of these stumps may have carried large stones which they finally dropped and so put an occasional "boulder" into the forming beds. These boulders must not be confounded with concretions.

ORIGIN AND DISTRIBUTION OF FOSSILS.

1305. Shells were imbedded in shore deposits, leaves and logs of high land plants and bones of land animals were drifted into swamps and buried in mud, and tracks were formed on flat muddy shores by animals walking on them. These have been preserved with more or less change. They are called **fossils.** There are multitudes of different fossils scattered through all the stratified rocks, but every group of rocks carries its own peculiar fossils, so that from the knowledge of them the truest key to the different formations is placed within our reach.

The best way to study the characteristic fossils of the various formations in which coal beds are known to occur is to visit any public or private collections within reach.

A study of the illustrations in this subject, and in other well-illustrated geological manuals, will greatly assist the student in familiarizing himself with the most common forms of fossils.

1306. Geological Fauna and Flora.—Generally speaking, the various animals belonging to the world constitute the geological fauna, and the plants and trees constitute the geological flora. Nearly every era, age, period, and epoch has a fauna and flora which have a marked distinction from those of other eras, ages, periods, and epochs.

1307. The Order of Superposition.—The order of superposition, and, therefore, the relative ages of the strata composing the rock series, were determined:

1. Independently.

2. By comparison, partly by the minerals and character of the rock (if the localities were contiguous), and partly by fossils.

In this way the geologist determines which strata in various localities were formed during the same period, and which strata are missing in some localities. In the widely separated districts, the comparison can be made only by fossils.

An indefinite number of limestones, sandstones, shales, and conglomerates are included in the stratified rocks of the earth's crust. They occur horizontally and displaced, conformable and unconformable. Even the same bed frequently changes its character in a very short distance from a sandstone to a shale, from a shale to a limestone or a conglomerate. Again, if it retains a uniform composition the color changes, so that it can not be recognized by appearance.

The sandstone of one district may be represented in another by a limestone of contemporaneous origin. Some rocks are found in the east of the United States which are not found in the west in the same age.

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Sand beds, mud beds, clay beds, pebble beds, and limestone beds all over different parts of the globe may have been forming during the same geological era.

A stratum of one age may rest upon any stratum in the whole series below it. For example, the coal measures may rest on the Archean, Silurian, or Devonian, and the Jurassic, Cretaceous, or Tertiary on any one of the earlier strata, the intermediate strata being entirely wanting.

The second object to be attained by classification is the division and subdivision of the whole series into larger and smaller groups, corresponding to eras, periods, and epochs of time.

The Geological Chart for North America gives an outline of the classification referred to. This classification is very important in the study of the Economic Geology of Coal.

UNSTRATIFIED, OR IGNEOUS, ROCKS.

1308. Igneous Rocks, which form the second class, are much more complex in structure and composition than aqueous, or stratified, rocks. They contain a great variety of minerals, and the minerals themselves are of great complexity. They are distinguished from stratified rocks by the absence of true stratification, by the absence of fossils, and by the difference in the mode of their occurrence. They are due to heat in some form.

1309. Igneous rocks occur underlying all the strata (see *K*, Fig. 352), forming the axes and peaks of nearly all

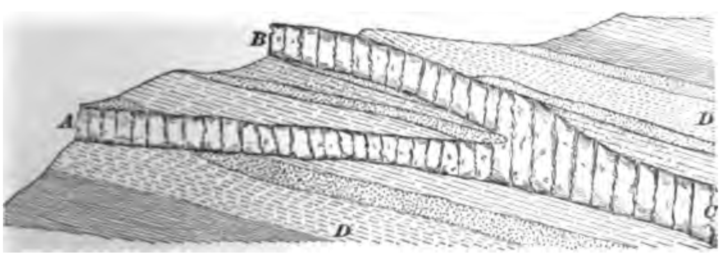

FIG. 364.

great mountain ranges (*J*, Fig. 352). They also occur in

vertical or nearly vertical sheets, filling great fissures in stratified rocks or other igneous rocks. Fig. 364 shows *A B C* cutting strata between *D D*, and is called intrusive. In Fig. 352, *2* shows a granite intrusion which, if it continued its outpour, would form a horizontal sheet overlying the strata *G*. When such intrusions, or dykes, cut coal seams they partially coke the coal (sometimes burn the coal completely, leaving only the ash), and bake the measures where they have come in contact with them.

1310. Igneous rocks may be classified as volcanic and plutonic. Most, but not all, volcanic rocks are recent. A volcano is simply a hole in the earth from which materials (gases, liquids, and solids) are at times expelled and scattered around the opening. (See Fig. 365.)

From the opening called the crater, masses of rock, torn

FIG. 365.

from the side, are hurled with the steam into the air; these strike against each other and, falling and being again ejected, are reduced to dust; this dust, with the coarser material, is often converted by rain into a mud, which is known as volcanic ash. This ash is spread in a more or less stratified manner; sometimes when it falls into the sea it is perfectly stratified, and may be mixed with various marine sedimentary matters, and may even contain fossils. Nevertheless it is proper to classify it as igneous rock.

If the cross-section of a volcano could be seen it would appear something like that shown in Fig. 366.

A, *A*, *A*, *A* are successive layers of lava and ashes

thrown up from below, at various stages of activity of the volcano. *V*, *V'* is what is called the *neck*, i. e., the crack or hole through which the materials of the volcanic mass have

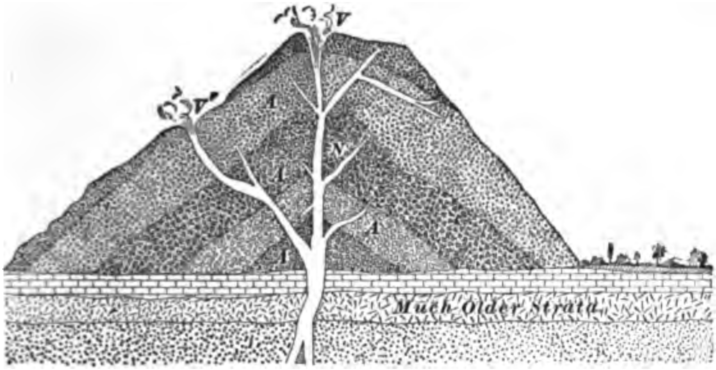

FIG. 366.

been ejected. This neck may have several branches, as shown, and from these, little volcanoes such as *V'* are often formed and become "active" at various periods.

1311. Lava produced by volcanoes is molten, or semi-molten, rocky material containing a large amount of water, which escapes from it in the shape of steam, filling the upper part of the stream of lava with bubbles and rendering it *light* and *cindery*. As it cools, it becomes very hard in the central portion, and sometimes a peculiar col-

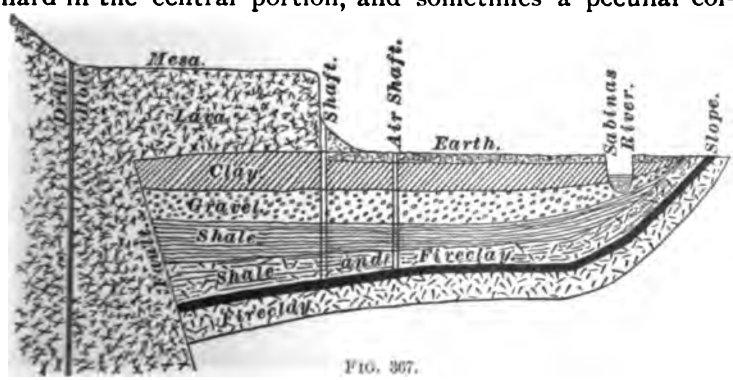

FIG. 367.

umnar appearance is developed by contraction in the act of cooling.

Sometimes the lava, instead of being poured out at the crater, or neck, is forced into and through the surrounding strata, either filling cracks and joints and forming *dykes*, or, in some cases, forcing itself in between two layers of rock and producing the appearance of having been *interbedded*.

Sometimes coal is found extending to a great length under a deposit of lava, as in Mexico. The lava which formed the Santa Rosa Mountains was thrown up and flowed over the strata containing the coal to a great distance from the point where the lava was pushed up through the coal and other soft strata. (See Fig. 367.)

1312. Plutonic Rocks.—There is no essential difference in composition between plutonic rock and volcanic rock. The difference is in texture. Plutonic rocks cooled and solidified at considerable depth in the earth; and, naturally, the cooling process went on more slowly, and the mineral materials were able to arrange themselves in a more or less crystalline form. The best known and most marked in character of this group are the granites and their allies.

METAMORPHIC ROCKS.

1313. All rocks have been changed, or metamorphosed, to some extent since their original deposition, but the term metamorphic applies only to those rocks which have been changed into crystalline rock, and, usually, without fusion. The rocks so changed were the ordinary fragmental rocks and limestones. The alteration, when most perfect, has consisted in a complete crystallization of the rock, and when least so, in its consolidation; between these extremes various conditions of partial metamorphism exist. Examples of metamorphic rocks are marble, mica schist, serpentine, gneiss, and much granite. All the lowest and oldest rocks are metamorphic. However, metamorphic rocks are not always among the oldest; metamorphism is no test of age. Metamorphic rocks are found in the Tertiary formations as well as in the Laurentian. Metamorphism is generally

associated with foldings, tiltings, intersecting dykes, and other evidences of igneous agency, and is, therefore, found in mountainous regions. It is also usually found in very thick strata.

1314. Effect of Metamorphism.—The effects of metamorphism include:

1. Simple compacting and solidifying, as in making a rock looking like granite from granitic sandstone.

2. A change of color, as the gray and black of common limestone to the white color or the clouded shadings of marble, and the brown and yellowish-brown of some sandstones, colored by iron, to red, making red sandstone and jasper rock.

3. In most but not all cases, a partial or complete expulsion of water; serpentine contains 13% of water.

4. An evolving and expelling of oil or gas, as when bituminous coal is changed to anthracite or to graphite.

5. An obliteration of all fossils, or, if the metamorphism is partial, of nearly all. The obliteration is usually preceded by the compression and distortion of the fossils.

6. Often a change in crystallization with little or none in chemical constitution, as when a limestone is turned to white statuary marble, and a sandstone or argillaceous rock, made from the granulation of granite, gneiss, and related rocks, is changed to granite or gneiss again.

7. In many cases a change of constitution, for the ingredients subjected to the metamorphic process often enter into new combinations, as a limestone with its impurities of clay, sand, phosphate, and fluorides, under the action of heat, forms white granular limestone, with various crystalline minerals disseminated through it, such as mica, feldspar, scapolite, pyroxene, apatite, etc.

1315. Theory of Metamorphism.—The subject of metamorphism is a very obscure one, but it may be divided into two kinds, viz., local and general.

Mechanical energy can be converted into heat. If a piece

of cold iron placed on an anvil is struck with a heavy hammer it becomes hot; the mechanical energy of the moving hammer disappears, and at the same time instant heat is developed. There is a direct relation between the heat manifested and the mechanical energy which disappears. The heat is produced in the iron by its sudden compression, and in the same manner when a great mass of strata sinks down by its own weight, the lateral pressure, which throws it into folds, also develops a very great amount of heat. This heat combined with water and great pressure probably brings about those changes in the rocks called metamorphism.

Local metamorphism is produced by direct contact with evident sources of intense heat, as when dykes break through stratified rock. Under these circumstances impure sandstones are changed into schists or gneiss, clays into slates, limestone into marble, and bituminous coal into coke, anthracite, or graphite. Near dykes of trap the rock is sometimes made cellular by escaping steam and filled with fissures, made by shrinking on cooling or drying. The waters of mineral springs, especially when heated, have produced metamorphic effects in the rock.

STRUCTURE COMMON TO ALL ROCKS.

1316. All rocks, whether stratified or igneous, are divided by cracks or division planes in three directions into

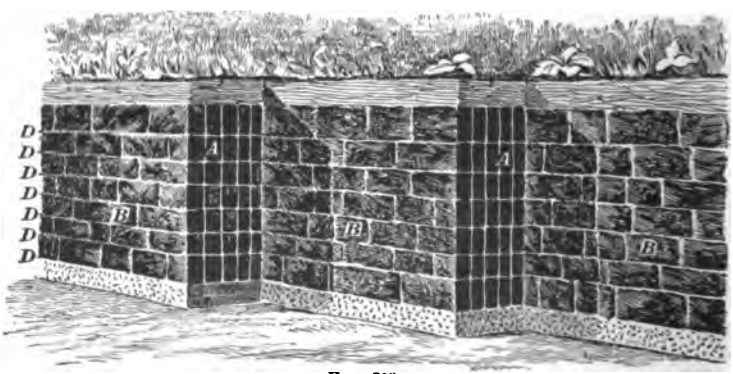

FIG. 868.

separate irregular prismatic blocks of various sizes and

shapes. These cracks are called **joints.** In stratified rocks the plane between the bedding constitutes one of the three division planes, which is called the **bedding plane,** while the other two are nearly at right angles to the bedding plane and to each other. They are true joints, sometimes called slips, and are known among mining men as **butt cleat** and **face cleat.** In some stratified rocks one of these last joints is well defined while the other may be rather irregular. In Fig. 368 the face cleat is shown at *A*, the butt, or end, cleat at *B*, and the bedding planes at *D*.

Fig. 369 shows slips, or cleats, as they appear in different coals. They are: (*a*) Inclined cleavage; (*b*) vertical cleavage; (*c*) irregular cleavage; (*d*) rhomboidal cleavage; (*e*) cone-in-cone cleavage; (*f*) shelly cleavage.

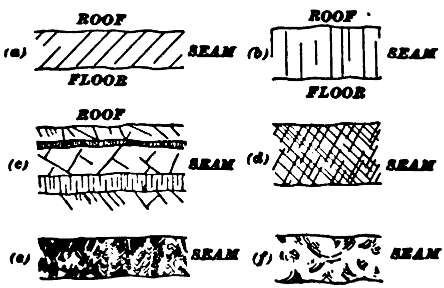

Fig. 369.

In sandstone, the blocks formed by these joints are large and irregularly prismatic; in slate, small, confusedly rhomboidal; in shale, long, parallel, straight; in limestone, large, regular, cubic.

In stratified rocks, these joints are all probably due to shrinkage in the act of consolidating from sediments, and in metamorphic rocks to shrinkage in cooling.

Fissures and fractures must not be confounded with joints; fissures are fractures in the earth's crust passing through several strata, instead of but one, as in the case of joints. Joints were probably produced by shrinkage and other causes, but fissures were produced by movements of the earth's crust.

1317. Cleavage.—Cleavage, in geology, has a different meaning from joints. Dana says: "Slates are often transverse to the bedding, that is, they often cross the layers of stratification more or less obliquely, instead of conforming to the layers, or bedding. Cleavage is, in this

respect, like the jointed structure, but it has the planes of fracture, or divisional planes, so numerous that the rock divides into slates instead of blocks, and the two differ in mode of origin."

Cleavage has been proved by experiments to result whenever fine-grained rock material is subjected to pressure, and to be due to the flattening of all air cells and compressible particles, and the arranging of all flat grains in planes at right angles to the pressure. The pressure producing upturning, or flexure, and also mountain making, has generally been the cause of cleavage in upturned or flexed strata of fine grain. It conforms to the bedding whenever the bedding is, as a consequence of the upturning, at right angles, or nearly so, to the pressure.

Flagstone, or lamination cleavage, crystalline cleavage, and organic cleavage are readily defined, but the remarkable cleavage we have been discussing has long excited the interest of geologists, and many theories have been advanced.

FAULTS.

1318. The dislocations produced in the earth's crust by the numerous agents are known by such terms as **faults, slips, hitches, heaves, wants, leaps, throws, troubles,** etc. Faults may be so thin as to be mistaken for the ordinary jointing of the rocks they traverse. More often, however, there is a considerable space between their walls, or cheeks. This space is sometimes filled with débris from the adjoining rocks, or with matter deposited from the solutions circulating within them. When filled up with injections, or intrusive matter, or infiltration of mineral matter, the dislocations are known as dykes, lodes, and veins.

These disturbances, where they traverse the coal measures, contain Carboniferous matter, which at times is accompanied by metallic minerals. There is no essential difference between faults found in the coal measures and the mineral veins of metalliferous districts.

1319. In the making of faults (*A H*, *J I*, Fig. 370), there is first a fracture, and then a shoving up or down of the beds

on one side of the fracture; i. e., a **down-throw** on one side, or an **up-throw** on the other. The amount of dis-

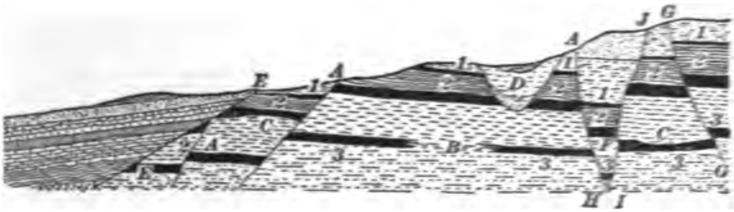

FIG. 20.

placement is the amount of fault; it may be a foot or less, or 10,000 feet or more.

1320. The position of a fault is defined by two directions; the strike of a fault is spoken of in the same sense as referred to beds, but in place of the word dip as referred to bed, in connection with faults the term **hade** is employed, this being, however, the inclination measured from the vertical. To determine a fault accurately two things must be known: 1. Which side is thrown up and which side is thrown down. 2. The amount of displacement. The former is in a majority of instances easily determined, as faults usually hade, or incline, towards the down-throw, so that in driving roads underground, if the fault is first met with in the roof, it is a down-throw, while if encountered on the floor first, it is an up-throw. Rock before breaking bends a little, and such signs are very useful to mining men, especially where the hade is nearly vertical; because if the coal turns upwards, it indicates an up-throw, but if the coal turns downwards, it indicates a down-throw. This is not, however, an invariable rule, for occasionally we find in the various coal fields, coal rising towards a down-throw, and *vice versa*. No rule can give the amount of displacement, as sometimes when the hade is small, the throw is large, and at other times with a similar hade, the displacement is very small. The throw of a fault is always measured vertically, and may be variable at different points, often changing from one foot at one end to hundreds of feet at the other.

When there is a lateral or oblique shove in a dislocation, as is often the case, the thickness of the bed on the two sides of the line of fault may differ; provided, the bed is not of uniform thickness throughout.

1321. The following definitions refer to Fig. 370:

(*A*) **Dislocations,** commonly termed "throws," "hitches," "slips," "jumps," &c., the amount of throw or displacement varying from a few inches to thousands of feet; that is to say, if in working a coal seam a nearly vertical wall of some other rock (other than a "clay vein") is met, it is possible that the coal bed has been faulted or thrown up or down to the extent mentioned.

(*B*) **Thinning out;** i. e., the stratum more or less suddenly thins down or becomes worthless as a mineral, due to one or more bands or seams of foreign material setting in and spoiling it.

(*C*) **Nips, rolls, horses,** mean that the roof comes down and takes the place of the coal, or the floor comes up and does the same thing—in some cases, both phenomena occur together.

(*D*) **Washouts, wants,** have practically the same effect upon the seam being worked, but have been produced by the removal or washing away of a portion of the seam, and the deposition in its place of sand or mud, afterwards converted into sandstone and shale. Washouts may affect more than one seam.

(*E*) **Denudation.**—This means that the seam, being followed, comes to an end against the surface or "modern" formations, or against stratified or unstratified rocks of some other period.

(*F*) **Trough Fault.**—A wedge-shaped fault, or, more correctly, a mass of rock, coal, etc., let down between two faults of dislocation dipping towards each other. These faults, however, are not necessarily of equal throw.

(*G*) **Overlap Fault.**—A peculiar kind of fault where a seam is reversed or doubles back over itself, as when one

end of the dislocation is thrust or forced over the other end. (See Fig. 371.)

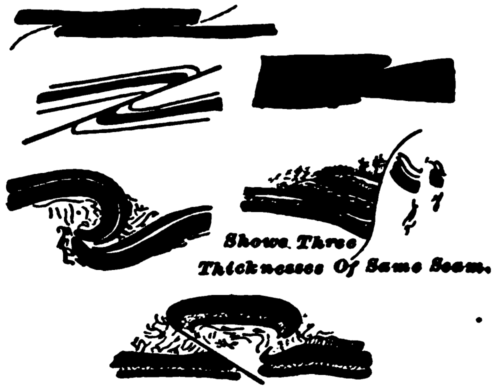

FIG. 371.

1322. These faults have been produced or formed in several ways or through several agencies. The throws *A*, *A*, *G*, Fig. 370, show that the whole series of strata affected has been rent asunder and upheaved, then fallen back and become as one solid mass again, the ends of the seams on right of *G*, *G* having been forced over the broken ends on the opposite side of the line of fracture, whereas the throw or slip at *A* shows that the beds on the left have slid downwards on that side.

1323. Clay Veins.—Clay veins may be termed faults, inasmuch as they break the regularity of the coal seams they traverse, and more or less spoil their quality. Such faults are merely clay-filled gashes or wide cracks formed by considerable movement of the seam soon after it was deposited.

1324. Wants or Washouts.—Since wants are usually filled in with irregularly stratified materials, they can usually be distinguished from dislocations, or throws, and by drifting through this body of mixed measures on the same pitch as the coal lay before the washout took place, the seam will generally be recovered without any difficulty.

"Pinch out" is a term used by American miners very much, and signifies the same thing as *nip*. In some coal fields, especially the lower coal seams of Tennessee, the coals pinch out, leaving sometimes the thinnest streak of black between sandstones by which the seam is traced to the next *pocket* or *basin*. The term *squeeze* is sometimes used in the same sense as pinch out.

Pennine fault is used to designate the eroded crest of an anticlinal axis, or saddle.

1325. Denudation means the wearing and carrying away of the solid materials of the land by wind and water. Rivers carry away portions of the land through which they flow; the tidal currents of the ocean lay bare the rocky materials of its shores.

The glacier has also been a great agent of denudation, for, as it moved, it cut great furrows, or valleys, in the earth and carried on its under side large masses of loose material, which it deposited miles away from the place of their origin.

Denudation is going on constantly, not only in the tremendous rending and grinding of the tidal waves, but in the rivers and streams as well. Their turbidity testifies that they are tearing down and carrying to the valleys the materials of the high lands.

Water acts chemically on limestones, and eats away this rock. The feldspar of granite and basalt generally contains potash, soda, or lime, which is attacked by the carbonic acid and converted into carbonate of potash, soda, or lime, and is carried away in solution.

Changes of temperature in the air cause rocks to split into many pieces; heat causes rocks to expand, and cold causes them to contract, and as the outside of the rock experiences the greatest change it splits off from the inner part. This disintegration produced by frost and grinding of boulders furnishes much of the material carried by running waters, and deposited to form new rocks under the waters of the sea.

Wind also performs a portion of denudation by blowing sand in arid and sandy regions, which cuts away exposed rocks and planes them down in no small degree.

The manner in which the strata outcrop in the coal regions may be said to be due to denudation.

1326. Complexities in stratified deposits are often due to denudation; strata are removed over extensive regions, the top or side folds are carried away, and various kinds of sections made of the stratified beds.

One of the simplest of these effects is the entire removal of the rock over more or less wide intervals (Figs. 355 and 372), so that the continuation of the strata is met with many miles distant. The result is more troublesome among the flexed, or folded, strata.

A series of close flexures, like (*a*), Fig. 372, worn off at the top down to the level of the line *a b*, loses all appearance of folds, and seems like a series of layers dipping in one direction. This is best seen from a single fold as (*b*), Fig. 372. If the top of the fold (*b*) were cut off at the line *a b*, there would remain the part represented in (*c*), in which there is

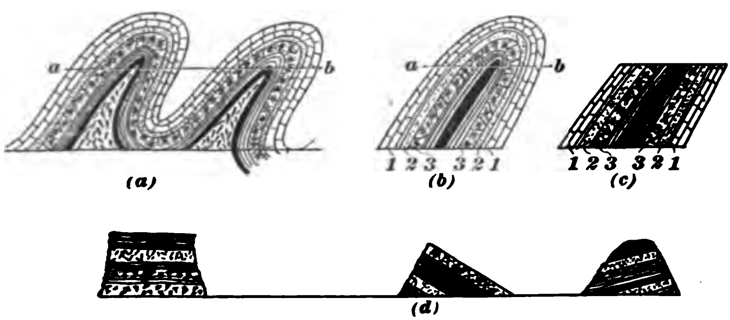

FIG. 372.

no appearance of any fold, and only a uniform series of dips. Although *3*, *2*, and *1* appear to be the lower strata of the series, they are actually parts *1*, *2*, and *3*. A long series of such folds, pressed together and then denuded, would make a series of uniform dips, obscuring wholly the true stratification.

This obscuring of the true succession has been greatly increased by denudation over great areas and filling up of

intermediate depressions by soil, so that the rocks are visible only at long intervals, as in (*d*), Fig. 372. Many of the difficulties in the study of rocks arise from this cause.

1327. In coal mining, the work of denudation is seen in wants or wash-faults, "pot-holes," etc. The latter (pot-holes) are deep hollows or excavations in the rocks, made by the grinding action of hard boulders agitated by turbulent water in the glacial period. Since formed, they have become filled in with stones, sand, and mud, and may be beneath rivers and lakes; hence the results of denudation sometimes seriously affect coal mining operations in an unexpected way. (Nanticoke, Pa., disaster in 1885.)

Denudation then is the opposite of deposition, but as deposition somewhere must go on at an equal pace with denudation there is no actual loss or waste of matter; it is simply the process of moving material from one place to another—tearing down one kind of rock to build up one of a totally different kind in a different locality.

1328. Another result or effect of denudation is that the accumulation of strata, composed of denuded older rocks, causes subsidence of the original crust over the area on which such new strata are deposited, and a corresponding elevation of the area denuded.

Applying this principle to mining, we may assume that the roof will cave in sooner, or to a greater extent, if a heavy culm pile exists over the worked area than if no culm were there to add to the weight. And where the floor is soft when the coal is removed, the bottom will rise, because the weight has been taken off it.

It does not follow that because a lower coal seam has been denuded locally, overlying ones will be similarly affected. This will usually depend upon what the want is filled up with; if with coal-measure material, then the upper seam will probably remain intact—undisturbed; but if sand, gravel, boulders, clay, etc., are there, the chances are the top coal is not there.

Extremely rare instances are on record of coal seams being denuded from underneath. Fig. 373 will illustrate what is meant.

In Belgium there are quite a number of open or empty pits, or a very deep kind of pot-holes traversing the coal measures, but they do not always extend upwards to the surface or even to the highest stratum of the coal measures.

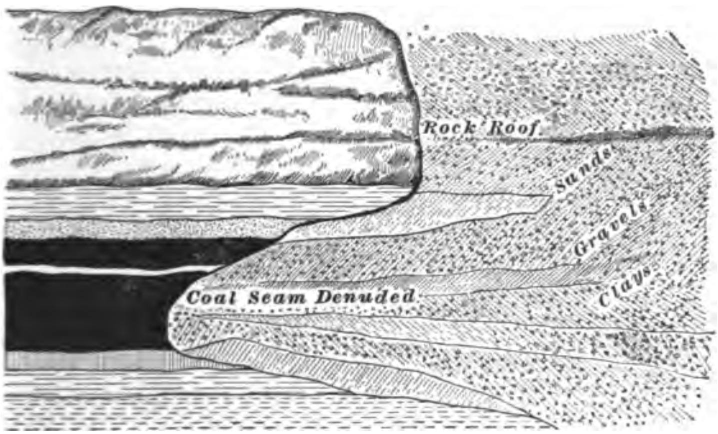

FIG. 373.

Some form of denudation would seem to have produced them.

1329. Thinning Away of Strata—Overlap.—It sometimes happens that two lines of outcrop come together, owing to the complete thinning away of the intermediate strata, and the conjoined outcrops may then be traceable for a long distance without further change. Instances of this kind sometimes occur among coal seams.

When the sea encroaches on the land, wearing away the cliffs and spreading out their waste materials in the form of shingle and sand upon the beach, the upper beds will spread over and cover up the lower ones.

This structure may frequently be met with along the margins of formations deposited in regions which at one time underwent gradual submergence.

HISTORICAL GEOLOGY.

PREHISTORIC ERAS.

INTRODUCTION.

1330. The earth's history is divided into geological eras, ages, periods, and epochs, and nature has recorded these in separate rock systems, rock series, rock groups, and rock formations. In geological history the eras and periods shade insensibly into each other; nevertheless, there have been times of revolutionary change. The divisions of time, especially ages, are characterized by the introduction and culmination of successive dominant classes of organisms, the highest expressions of earth life. Thus, we have an age of mollusks, an age of fishes, an age of reptiles, in which these were in their turn the dominant class.

Unconformity of the rock system and change in the life system are the two modes we have of determining and limiting eras, ages, periods, etc. Unconformity indicates blanks in the known record furnished by the rock system, rock series, and rock formations, but the most important changes in the life system of the eras, ages, periods, etc., ought to, and usually do, correspond with the unconformity of the rock system. When there is discordance, as there sometimes is, we should rather follow the life system than the rock system.

1331. There are five eras with corresponding rock systems in the earth's history, viz.: (1) Archean, or Eozoic (dawn of animal life), embodied in the Laurentian system; (2) Paleozoic (old life), embodied in the Paleozoic, or Primary system; (3) Mesozoic (middle life), recorded in the Secondary system; (4) Cenozoic (recent life), recorded in the Tertiary and Quaternary systems, and (5) Psychozoic (or era of mind), recorded in the recent system.

These grand divisions, with the exception of the last, are founded on almost universal unconformity of the rock system, and a very great and apparently sudden change

affecting species, genera, families, and even order in the life system.

1332. There are also seven ages in the earth's history founded, excepting the first, on the culmination of certain great classes of organisms: (1) The Archean, or Eozoic age, represented by the Laurentian system of rocks; (2) the Age of Mollusks, or Age of Invertebrates, represented by the Silurian system of rocks; (3) the Age of Fishes, represented by the Devonian rocks; (4) the Age of Acrogens, or sometimes called the Age of Amphibians, represented by the Carboniferous rocks; (5) the Age of Reptiles, represented by the Secondary rocks; (6) the Age of Mammals, by the Tertiary and Quaternary, and (7) the Age of Man, by the recent rocks.

ARCHEAN ERA.

1333. Laurentian System of Rocks.—The study of the Canadian rocks, by Sir William Logan, revealed that the highly metamorphic rock which was apparently destitute of fossils and had been known to exist below the lowest Paleozoic rocks was everywhere unconformable with the overlying Cambrian. This established the fact of its being a distinct system of rocks and a distinct era. The only distinct character of the Laurentian rock is the extreme and universal metamorphism of the rock, which consists of altered sandstones, limestones, and clay, as in most other metamorphic rock. Interstratified with the schist, quartzite, and marble are immense beds of iron ore, over 100 feet thick, and great quantities of graphite. This graphite impregnates the rocks, and sometimes is found in pure seams, indicating organic matters which were chiefly vegetable, for graphite is only the extreme term of the metamorphism of coal.

The existence of rhizopods, one of the great limestone builders of subsequent geological epochs, is believed to be demonstrated. This supposed specimen has been called Eozoon Canadense (dawn animal).

PALEOZOIC ERA.

1334. The history of the world from the beginning of the Primary or Paleozoic era is comparatively easy to follow. This era reveals a distinct life system and a distinct rock system, being everywhere unconformed to the Laurentian below, and the Secondary above. The life system of this era is abundant (more than 20,000 species having been described) and distinct. There is a very marked difference in the Primary life system from the life system which precedes and that which follows.

1335. The Paleozoic era is divided into three ages, which are embodied in three distinct subordinate rock systems. These ages are characterized by the dominance of a great class of organisms. (1) Silurian system, or Age of Invertebrates, or sometimes called the Age of Mollusks; (2) the Devonian system, or Age of Fishes, and (3) the Carboniferous system, or Age of Acrogens and Amphibians.

In the United States these three systems are generally conformable, but elsewhere they are often unconformable. Of the interval between the Archean and Paleozoic, nothing will be said here, as it is intricate and has scarcely any bearing on the Economic Geology of Coal.

1336. Silurian System.—The following table gives the divisions and sub-divisions of the rocks and the corresponding periods of the age in this country:

Silurian	Upper Silurian	Lower Helderberg Period.
		Salina Period.
		Niagara Period.
	Lower Silurian	Trenton Period.
		Canadian Period.
	Cambrian or Primordial	Potsdam Period.
		Acadian Period.

It may be said that the Cambrian contains the earliest

known fauna. It is true the lowest rhizopods probably existed in Archean times, but these can not be said to constitute a fauna. It must be remembered that between the Archean and Paleozoic there is a lost interval of enormous duration. Evidently, therefore, the Cambrian fauna is not the actual first fauna. In the United States and Canada about 400 species are known in the Cambrian, of which nearly 100 are trilobites, and in the lowest zone of the Cambrian, viz., olenellus beds, there are 134 species, of which 55 are trilobites. About a dozen plants are also known.

In most of the periods of the Silurian, there was evidently great abundance and variety of life. The number of individuals and species was probably not less than at the present time. Over 10,000 species have been described from the Silurian alone, and they must be regarded as a small part of the actual fauna of that age. The trilobite of the genus Paradoxides, shown in Fig. 374, as Nos. 9 and 10, exists in the Acadian epoch, none of which is known afterwards.

Le Conte says: "In certain favored localities, the number of species found in a given area of a single stratum (Silurian Age) will compare favorably with the number now existing in an equal area of our sea bottoms. Yet in all this teeming life, there is not a single species similar to any found in any other geological time."

1337. Plants.—*Marine algæ*, or seaweed, called fucoids (Fucus, tangle or kelp), or fucus-like plants are the only forms observed. Some of the fossils, formerly regarded as indications of plants, are now believed to be worm tracks, or borings.

1338. Animals.—The species observed are all invertebrates. They pertain to the four sub-kingdoms, Protozoans, Radiates, Mollusks, and Articulates.

The Articulates were represented by worms and crustaceans; the Mollusks by brachiopods, pteropods, gasteropods, and cephalopods; Radiates, by crinoids. No evidence has

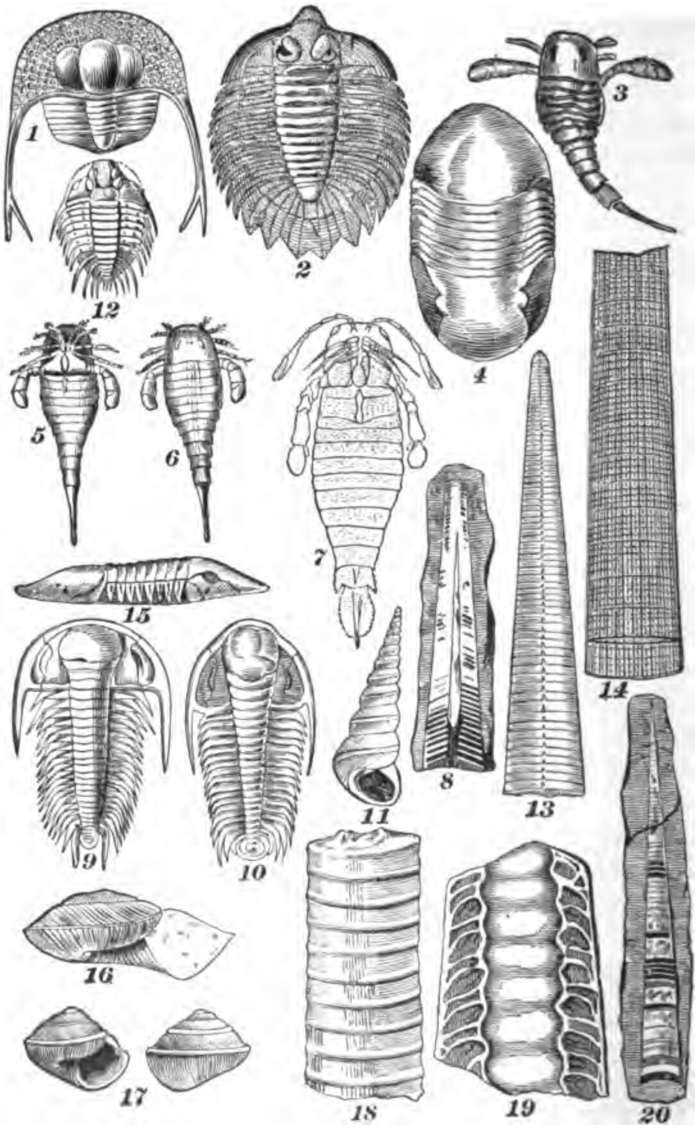

FIG. 374.


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FIG. 374.

yet been found of the existence of polyps among Radiates; or, in the earlier epoch, of lamellibranchs among Mollusks.

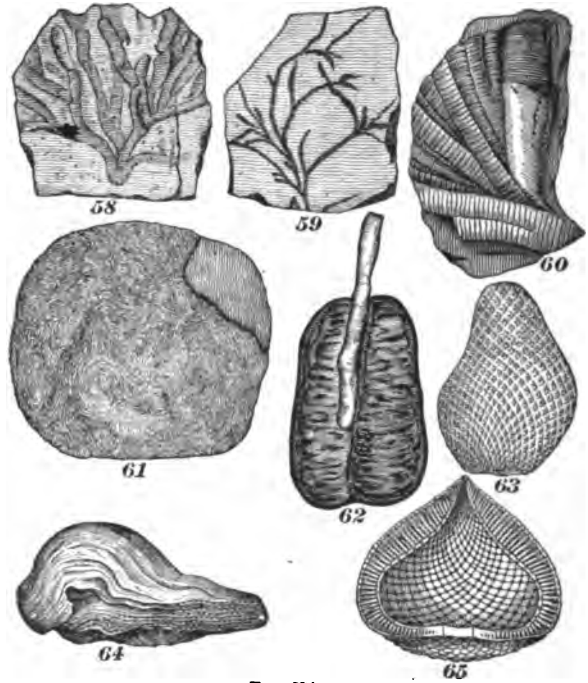


FIG. 874.

Barrande's table showing the number of Silurian species:

Sponges and other Protozoans	153
Corals	718
Echinoderms	588
Worms	185
Trilobites	1,579
Other Crustaceans	348
Bryozoans	478
Brachiopods	1,567
Lamellibranchs	1,086
Heteropods } Pteropods }	390
Gasteropods	1,306
Cephalopods	1,622
Fishes	40

Thin layers of carbonaceous matter are occasionally met in the Silurian, and even, as stated by Murchison, a small bed of anthracite from one to twelve feet thick has been found in the lower Silurian, the material for its formation apparently having been derived from masses of seaweeds.

Coal has been mined in Portugal from the Silurian formations.

We here give some specimens of the principal fossils of the Silurian Age (Fig. 374).

DEVONIAN SYSTEM, OR AGE OF FISHES.

1339. The only plants (Fucoids) found in the Silurian continue, though under different species, in Devonian times. In addition to the fucoids, land plants in considerable number and variety and decided complexity of organization are now introduced. They include ferns, lycopods, and equisetæ, and also conifers; and, by their great size and numbers, probably formed the first true forest vegetation. These plants are similar to those found in the Carboniferous. In the Devonian we find dark bands between the strata, impregnated with carbonaceous matter, and also thin seams of coal, with underclay filled with ramifying rootlets. The coal measures, therefore, are here found imperfectly developed.

Insects made their appearance in the Upper Silurian in the form of cockroaches and scorpions, but in the Devonian for the first time insects are found in great numbers in conjunction with the abundant vegetation.

The characteristic of the Devonian Age, the dominant class, Fishes, is introduced here. This is a new department, which introduces the vertebrates, a great step in the progress of life. The Devonian fishes were all ganoids and placoids. Commencing in the Upper Silurian, few in number, small in size, and of a strange unfishlike form, with the opening of the Devonian Age, fishes greatly increased in size and numbers, until the waters fairly swarmed with them. Never since have fishes apparently been so abundant

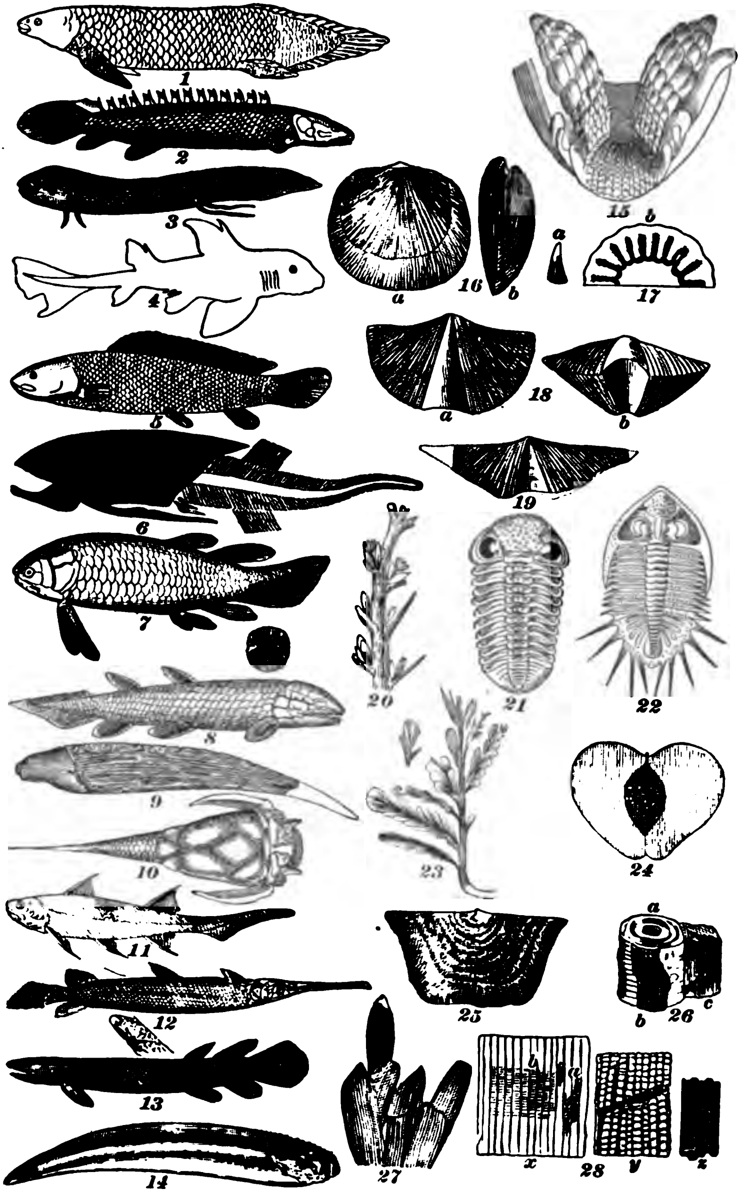


FIG. 875.

or of greater size. And yet all the species, genera, and families of the Devonian Age are now extinct.

In the Devonian are situated some of the coal fields of northwest France, as in Mayenne.

Specimen fossils of the Devonian Age are shown in Fig. 375.

CARBONIFEROUS SYSTEM, OR AGE OF ACROGENS AND AMPHIBIANS.

1340. This is the most important age in the world's history, so far as the human race is concerned. Its coal beds have contributed much to the prosperity and power of this country.

As stated before, the Carboniferous system, or age, is subdivided into three periods:

1. Sub-Carboniferous was the period of preparation.
2. Carboniferous (lower coal measures and upper coal measures) was the period of culmination.
3. Permian was the period of decline and transition to the Mesozoic Age.

The Sub-Carboniferous may be said to be the preparatory marine period upon which the Carboniferous was built. Deposits of coal in this period are sometimes called *false coal measures*.

In Montgomery County, Virginia, there is a seam of coal, 2 to 2½ feet thick, resting on a bed of conglomerate, and 30 to 40 feet higher is another layer, 6 to 9 feet thick, consisting of alternating coal and slate. Lesley says there is a coal bed (and possibly two) in the lower group, at Tipton, Pennsylvania, at the head of the Juniata, 600 feet below the upper shales.

The edge coals, in Scotland, an exceedingly valuable deposit occurring in the mountain limestone below the millstone grit, belong to this period.

The land vegetation of the Sub-Carboniferous period was very similar to that of the lower part of the Carboniferous Proper. There were lycopods of the tribes of Lepidodendron and Sigillaria, and various ferns, conifers, and calamites. Although the circumstances were less favorable for the

growth of vegetation and accumulation in marshes, the essential prerequisite for the formation of large beds of coal, the vegetation may have been just as profuse for the amount of land.

The animal life was remarkable for the great profusion and diversity of crinoids, pentremites, echinoderms, and lithostrotion.

1341. The Carboniferous Proper.—Like other formations, the Carboniferous Proper consists of thick strata of sandstone, shales, and limestones, having interbedded thin seams and beds of iron ore. In the Appalachian coal fields mechanical sediments, shales, and sandstones are thickest, while in the Western coal fields organic sediment, or limestones, predominates.

Le Conte says: "In the Carboniferous Proper period are still enclosed nine-tenths of all the worked coals, and probably nine-tenths of all the workable coals in the world."

In the richest coal fields there are 50 feet of rock for every foot of coal.

In comparing one coal field with another, or in the same coal field, in comparing one portion of the coal series with another, a regular order of succession has not been discovered, excepting that immediately below the seam and in contact with it is a fine fireclay which is a constant attendant, called *underclay*.

Frequently, just above the coal and forming the roof is a slate impregnated with a carbonaceous matter, which is not so constant as the underclay, and is sometimes replaced by sandstone or limestone. This was caused by a progressive subsidence until the seam had been buried under sand and mud forming the sandstone, or after the subsidence and clearing of the water, marine forms of life, zoophytes, encrinites, and mollusks made their way into the area for a period long enough to form a bed of limestone as roofing to the coal.

1342. As was said before, there is no fixed superposition of the rocks forming the coal measures. The following is an example from Western Pennsylvania, as published by

Lesley; the beds are numbered in accordance with their succession, beginning below, the lowest being given first:

		Feet.
A.	Millstone grit (sometimes called Farewell rock)	?
1.	Coal No. A, with 4 ft. of shale	6
2.	Shell and mud rock	40
3.	Coal No. B (of mammoth bed of central Pa.)	3–5
4.	Shale, with some sandstone and iron ore	20–40
5.	Fossiliferous limestone	10–20
6.	Buhrstone and iron-stone	1–10
7.	Shale	25
8.	Coal No. C, the Kittanning cannel	3½
9.	Shale—soft containing two beds of coal 1'–1½'	75–100
10.	Sandstone	70
11.	Coal No. D, Lower Freeport	2–4
12.	Slaty sandstone and shale	50
13.	Limestone	6–8
14.	Coal No. E, Upper Freeport	6
15.	Shale	50
16.	Mahoning sandstone	75
17.	Coal No. F	1
18.	Shale, thickness considerable	?
19.	Shaly sandstone	30
20.	Red and blue calcareous marlytes	20?
21.	Coal No. G	1
22.	Limestone, fossiliferous	2
23.	Slate and shales	100
24.	Gray clayey sandstone	70
25.	Red marlyte	10
26.	Shale and slaty sandstone	10
27.	Limestone, non-fossiliferous	3
28.	Shales	32
29.	Limestone	2
30.	Red and yellow shale	12
31.	Limestone	4
32.	Shale and sand	30
33.	Limestone, with bands of spathic iron ore	25
34.	Coal No. H, Pittsburg	8.9

The coal measures from the bottom (No. 1) to No. 15 in this section are *sometimes* designated the *lower coal measures*. Of the rest, or upper division, Nos. 16 to 33 are called *barren measures*.

1343. In different regions the rocks of any age are distinguished from those of other ages, not by their color or kind, nor by their succession, but by the species of fossil plants and animals they contain. In different parts of the same coal field at the same geological horizon, we are apt to find the same order, because it would be the natural result of the continuity of the strata over the whole basin.

In most cases, coal fields are basin shaped, i. e., they thin out on all sides as they approach their limit and are surrounded by older rocks, somewhat like a picture set in a frame. This is due in all probability, in many instances, to the original form of the area in which they were deposited. Or, the basin, in some cases, perhaps most cases, is due to disturbance of position that has taken place since the rocks were deposited. The strata, by movement of the earth's crust, have been thrown into folds, sometimes wide and gentle, sometimes very abrupt, and when the crests of these folds have been removed by subsequent denudation, areas once continous have been left as isolated, basin-shaped remnants.

1344. Source of Coal.—Eminent geologists advance two theories for the source of coal, viz.: (1) the coal was formed on the spot where the forest grew; (2) the coal was the result of accumulated drift. All agree, however, that it is the result of the decomposition of vegetable matter. The theory most generally accepted is the former, or a combination of both, although it is perfectly clear that, in a few instances, areas of coal have been formed by organic matter drifted into lakes.

1345. Mode of Growth.—Le Conte, speaking of *peat*, the first state of coal, says: "Plants take the greater portion of their food from the air, and give it, by the annual fall of leaf and finally by their own death, to the soil. Thus is

formed the humus or vegetable mold found in all forests. This substance would increase without limit were it not that its decay goes on simultaneously with its formation. But in peat bogs and swamps, the excess of water and, still more, the antiseptic property of the peat itself prevent complete decay. Thus, each generation takes from the air and adds to the soil continually and without limit. The soil which is made up entirely of this ancestral accumulation continues to rise higher and higher, until the bog often becomes higher than the surrounding country, and, when swollen by unusual rains, bursts, and floods the country with black mud. A bog is, therefore, composed of the vegetable matter of thousands of generations of plants. It represents so much matter drawn from the atmosphere and added to the soil. In such cases, besides the material deposited from the growth of vegetation, the accumulation may be partly also the result of organic matter drifted from the surrounding surface soil."

Peat is disintegrated and partially decomposed matter composed of carbon, with small and variable quantities of hydrogen, oxygen, and nitrogen.

Dana says: "There is no reason to suppose that the vegetation was confined to the lower lands; it probably spread over the whole continent (American Continent) to its most northern limits. It formed coal only where there were marshes, and where the deposits of vegetable débris afterwards became covered by deposits of sand, clay, or other rock material."

1346. The theory that coal has been accumulated by growth of vegetation *in situ*, as in peat swamps of the present date, is supported by the purity of the coal in some of the coal fields of America, the ash not being greater than would result from the plants of which it is composed. In extensive peat swamps, absolutely pure vegetable accumulations, unmixed with sediment, occur; but in buried rafts of drifted vegetable matter of any kind, there must be a large admixture of mud. The theory is further supported by the most complex and delicate parts of the plants, in their natural relation to each other, being preserved.

Again, we find these perfect specimens only in the upper part of the seam, as would be the case with the last fallen leaves. In drifted matter, they would be promiscuously mixed throughout the seam. The presence of stumps, with their spreading roots penetrating the under clay exactly as they grew, is a very important argument in behalf of the *in situ* theory. The underclay of every one of the 100 seams of coal in South Wales is crowded with roots and sometimes stumps. Of the 76 seams in Nova Scotia, 20 have stumps standing in their original positions, with spreading roots penetrating the clay. The other seams have each its under clay filled with stigmaria roots.

1347. Alternation of Peat with Sediment.—It is necessary to go a step further to account for the clays, sands, and limestones often interstratified with a bed of coal. To account for sand, etc., interstratified with the coal beds, it must be assumed that peat was deposited at the mouths of rivers, and that the foreign strata in coal are due to the sediment brought down by the rivers and laid over the successive layers of peat that formed the coal beds.

A section of the delta deposits of many great rivers reveals alternate layers of fresh water and marine sediment, with thin layers of peat, which accounts for seams of coal being practically one seam at certain points, with the smallest conceivable parting of sediment, which gradually separate until this small parting may have thickened to many feet.

Coals seams, especially thick ones, are very apt to "split," i. e., become horizontally divided into two or more separate beds, by the intervention of layers of ordinary strata of coal measures, such as clay, shales, sandstones, etc.

At *A* (Fig. 376), we have a thick coal seam with little or no parting in the middle, while at *B*, 1,500 feet away from *A*, no less than 30 feet of strata come in between the upper and the lower benches of the same seam. These 30 feet of rock got there in this way: After the bottom bench had formed, it subsided towards *B*, and went on going down, as one by one each layer of sediment, *1*, *2*, *3*, and *4*, was de-

posited on top, and as far as it could reach (for depth of water and other conditions prevailing at the time) towards *A*. Then came the formation or accumulation of the upper

FIG. 376.

bench of coal right over the top of both coal at *A* and strata at *B*, and of course beyond, until conditions changed again.

In Staffordshire, England, the "Ten Yard" coal has been proved to split up in a N E direction into no less than ten separate seams of coal in 500 feet of strata, and this in a distance of only five miles.

Fig. 377 is a section of a 30-foot coal seam *C C* which is replaced by 60 feet of rocks and slates at *A B*. The lower

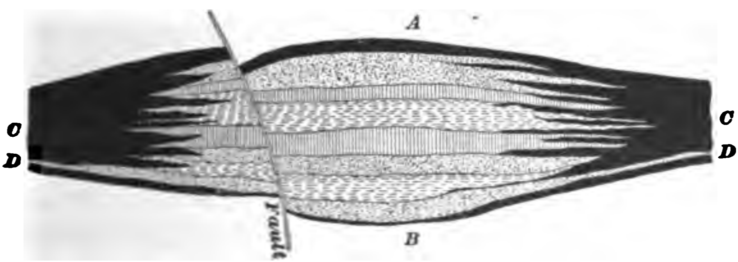


FIG. 377.

seam *D D* is also cut out and replaced at *B* by the same *horse*.

This horse measured 1,200 feet by 804 feet by 60 feet thick in the middle, tailing or thinning out on all sides to nothing.

1348. The Gradual Change from Wood to Anthracite.—To illustrate the gradual change in composition in passing from wood to peat, to lignite, to bituminous, and to anthracite, Dr. Percy gives the following table.

In this table Dr. Percy gives the proportions of hydrogen, oxygen, etc., to each 100 parts of carbon:

F. II.—4

TABLE 28.

	Carbon.	Hydrogen.	Oxygen.	Disposable Hydrogen.*
Wood (mean of several analyses)	100	12.18	83.07	1.80
Peat	100	9.85	55.67	2.89
Lignite	100	8.37	42.42	3.07
Ten yard seam of S. Staffordshire (Bituminous)	100	6.12	21.23	3.47
Steam coal	100	5.91	18.32	3.62
Anthracite	100	2.84	1.74	2.63

AMERICAN COAL FIELDS OF THE CARBONIFEROUS AGE.

1349. 1. Eastern border region, or Rhode Island coal field, a small area in Rhode Island extending northwest into Massachusetts. Area, 500 sq. miles.

2. Michigan, or Interior coal field, an isolated area wholly contained within the lower peninsula of Michigan. Area, 6,700 sq. miles.

3. Central coal field, Illinois, Indiana, and Western Kentucky, sometimes called the Eastern Interior coal field. Area, 47,000 sq. miles.

4. Appalachian or Alleghany Area.—This is the most important coal field in the world. It commences in Northeastern Pennsylvania, and covers the whole coal area of Pennsylvania and Eastern Ohio, and a large portion of Virginia, West Virginia, and Eastern Kentucky, and passes southward through East Tennessee, Northwest Georgia, and ends in middle Alabama. Area, 50,000 sq. miles.

5. Western coal field, or Western Interior Area.—This coal field covers a large portion of Missouri and extends north into Iowa and south, with interruptions, through Arkansas and Indian Territory into Texas, and west into

* Disposable hydrogen is that portion of hydrogen available for heating purposes in fuel, which is in excess of the quantity required to form water with the oxygen contained in the coal.

Kansas and Nebraska. The Illinois and Missouri areas are connected only through the Sub-Carboniferous rocks of the Carboniferous Age. But it is probable that formerly the coal fields stretched across the channel of the Mississippi, and that the present separation is due to erosion along the valley. Area, 98,000 sq. miles.

6. Acadian coal field, or the Nova Scotia and New Brunswick Area.—This is a large area on both sides of the Bay of Fundy. Estimated area, 18,000 sq. miles.

Besides these in the Carboniferous Age, there are the following barren, or nearly barren, areas:

1. The Rocky Mountain and Pacific Border region, embracing the Great Basin and Summit Area, containing parts of Montana, Wyoming, Colorado, Utah, and Nevada. Also, the California area in Northern California.

2. The Arctic Region, on Melville Island and other islands between Grinnell Land and Banks Land, on Spitzbergen and on Bear Island, north of Siberia.

Other American coal fields will be described when treating of the Cretaceous and other formations.

1350. Plication.—Coal seams and the strata containing them were originally horizontal and continuous; but they are now found sometimes horizontal and sometimes dipping at all angles, and folded in a most complex manner. In the Appalachian region, especially in the anthracite districts of Northeastern Pennsylvania, the strata are much disturbed and the coal seams interstratified with them are

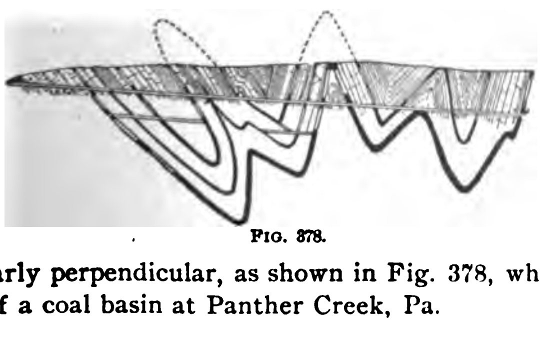


FIG. 378.

often nearly perpendicular, as shown in Fig. 378, which is a section of a coal basin at Panther Creek, Pa.

The coal is anthracite where the rocks are most disturbed, and going westward into regions of less disturbance, the proportions of bitumen, or volatile substances, increase quite regularly. It appears as if debituminization of the coal had taken place from some cause connected with the uplifting.

This will be seen in passing from the anthracite to semi-anthracite and to bituminous in Pennsylvania. The anthracite coal beds of Eastern Pennsylvania correspond in all respects, except that of hardness, to the bituminous beds of Western Pennsylvania, and, no doubt, originally united with them in continuous sheets over the length and breadth of the State. The debituminization of the Rhode Island coal shows a more marked effect. The coals were not only altered by the uplifting to an excessively hard anthracite, but to a graphitic coal.

1351. Varieties of Coal.—The varieties of coal depend upon the degree of bituminization, upon the proportion of fixed volatile matter, and upon the purity.

Le Conte says: "Coal consists partly of organic or combustible matter, and partly of inorganic or incombustible matter. On burning coal the organic combustible matter is consumed and passes away in the form of gas, while the inorganic incombustible is left as ash. Now, the relative proportions of these may vary to any extent. We may have a coal of only 2% ash. We may have a coal of 5, 10, 15, or 20% ash; the coal is now becoming poor. We may have a coal of 30 or 40% ash; this is called **bony** or **shaly coal**; it is the valueless refuse of the mines. We may have a coal of 50 or 60% ash; but now it loses the name of coal as well as the ready combustibility of coal, and is called **coaly shale.** Finally, we have the coal of 70%, 80%, 90%, or 95% ash; and thus, it passes, by insensible degrees, through black shale into perfect shale. This passage is often observed in the roof of a coal mine." This shows the varieties depending on purity.

Brown coal and lignite are examples of imperfect coal, showing varieties depending on the degree of bituminization.

The varieties depending on the proportion of volatile matter are not so simple of definition. However, there can be little doubt that these varieties are produced by slight differences in the nature and degree of chemical change in the process of bituminization.

1352. Metamorphic Coal.—The normal coal produced by metamorphism is probably not bituminous, while anthracite and graphite are the extreme forms resulting from an after change produced by heat; this heat which changes the coal has distilled away the volatile matter.

Another view is that bitumen is not necessarily correlative with anthracite. It is probable that the heat of metamorphism is not sufficient to produce destructive distillation. Such a degree of heat would hasten the process first described. The folded edges of the seam would still further hasten the process and bring about anthracitism by facilitating the escape of the products of decomposition. In all coal mines CO_2, CH_4, and H_2O are being eliminated now; only continue this process long enough, and anthracite and finally graphite will follow. It is a safe conclusion, then, that very high heat is not essential to produce anthracitism.

1353. Coal Flora.—The coal flora is one of the most abundant and perfect of the extinct floras. There are 8,660 known fossil species of plants, and of these 2,000 belong in the coal measures.

The coal plants are found principally in the form of stumps and roots in their original position in the underclay; in the form of leaves and branches and flattened trunks, on the upper surface of the coal seam, and in the overlying shale; in the form of logs, apparently drift timber, in the sandstones about the coal seams.

The fern is the most abundant, but the following are in great numbers as well: conifers, lepidodendrids, sigillarids, and calamites.

1354. A large number of these specimen fossils are shown in Figs. 379, 380, and 381. Their names are as follows:

1, welwitschia; *2*, a conifer leaf of half natural size of living congener; *3*, alethopteris lonchitica; *4*, neuropteris flexuosa; *5*, callipteris sullivanti; *6*, pecopteris strongii, showing fructification, (*a*) a leaflet; *7*, alethopteris massilonis; *8*. odontopteris wortheni; *9*, alethopteris (7) enlarged;

FIG. 379.

10, phyllocladus, a branch; *11*, salisburia, a branch; *12*, section of fruit of salisburia; *13*, *14*, *15*, *19*, *20*, *22*, *25*, and *26*, cardiocarpon; *23* and *24*, rhabdocarpon; *18*, *27*, and *29*, trigonocarpon; *16*, neuropteris flexuosa; *17*, hymen-

ophyllites alatus; *21*, pecopteris strongii; *28*, neuropteris hirsuta; *30*, *31*, and *32*, spirifer plenus; *33*, productus mesialis; *34*, phillipsia lodiensis; *35*, chonetes dalmaniana; *36*, productus punctatus; *37*, ptyonius; *38*, euproops danæ;

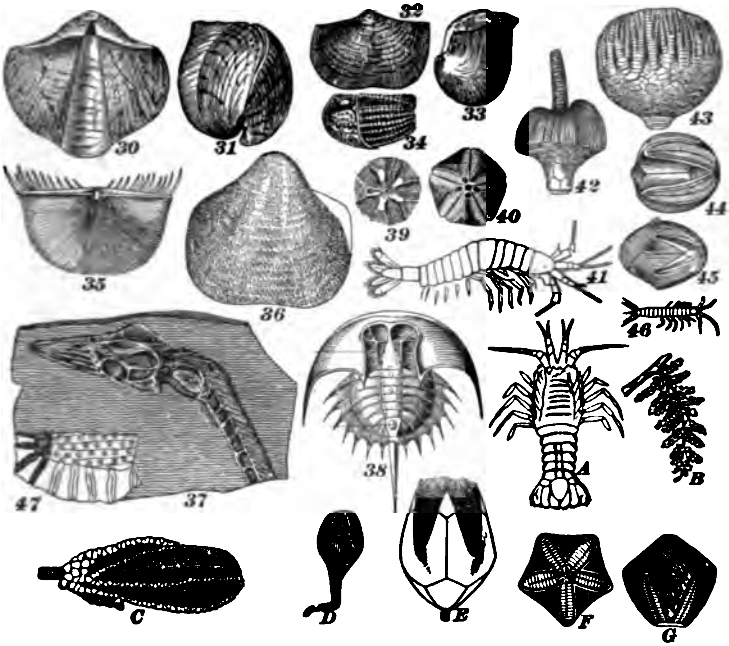


FIG. 380.

39 and *45*, pentremites gracilis; *40* and *44*, pentremites burlingtoniensis; *42*, batocrinus chrystii; *41*, paleocarus typus; *46*, acanthotelson stimpsoni; *47*, stigmaria ficoides; *A*, anthrapalemon gracilis; *B*, sphenopteris; *C*, scaphiocrinus scalaris; *D*, pentremites pyriformis; *E*, pentremite restored; *F* and *G*, pentremites cervinus; *H*, lepidostrobus; *I* and *J*, sigillaria restored; *K*, lepidodendron modulatum; *L*, lepidodendron diplotegioides; *M*, sigillaria greseri; *N*, lepidodendron rigens; *O*, sigillaria levigata; *P*, sigillaria reticulata; *Q*, lepidophloios acadianus, fruit; *R*, calamite, restored; *S*, lepidodendron corrugatum, branch and fruit; *T*, sigillaria

obovata; *U*, asterophyllites foliosus; *V*, lepidodendron corrugatum, branch and leaves; *W*, lepidodendron politum;

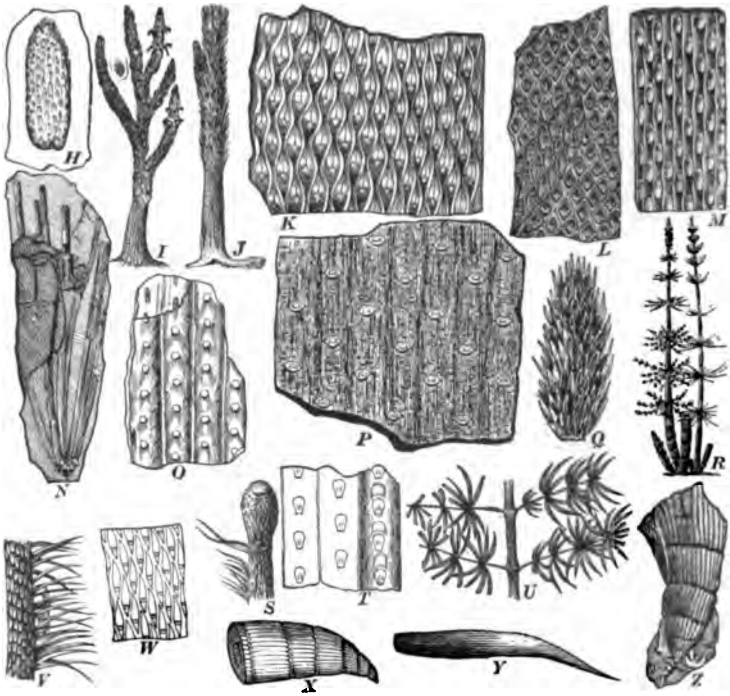


FIG. 881.

X, calamites, lower end of stem; *Y*, leaf of sigillaria elegans; *Z*, calamites canneformis, lower end of stem.

NOTE.—Stigmaria, so called on account of the round spots (*stigma*) on the surface, are now known to belong to sigillarids and lepidodendrids, and are either roots or spreading rhizomes (underground branches).

PERMIAN PERIOD, OR TRANSITION PERIOD.

1355. The Mesozoic rocks, excepting in the Rocky Mountain region, are universally unconformable on the Carboniferous, and with this unconformity there is a great change in the fauna. *In all cases* of unconformity of the entire geological formations, there is a lost interval, but in some cases greater than in others. In the interval here

(the Permian), many leaves of record have been recovered, while in the other *intervals*, not a leaf of record has been discovered.

Until recently nothing of interest in the American Permian has been found, except a few shells, but Europe furnishes a larger number of fossils. Permo-Carboniferous furnishes coal in North America, Bohemia, and in France.

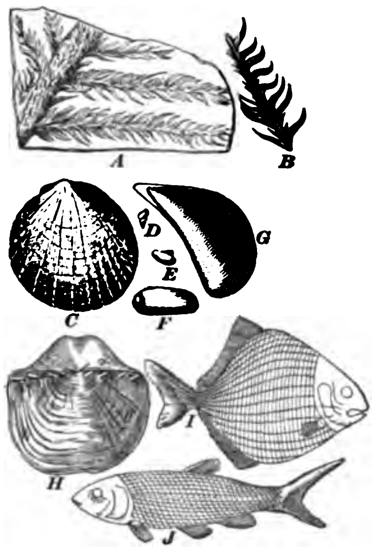


FIG. 382.

In Fig. 382 are shown specimens of the Permian fossils. They are:

A and *B*, walchia piniformis (Permian of Europe); *C*, eumicrotis hawni; *D*, gasteropod; *E*, bakewellia parva; *F*, pleurophorus subcuneatus; *G*, myalina permianar; *H*, pseudomonotis; *I*, platysomus gibbosus; *J*, restoration of paleoniscus.

MESOZOIC ERA, OR AGE OF REPTILES.

1356. This era is divided into three periods:

1. Triassic, because of its three-fold development where first studied in Germany.

2. Jurassic, because of the development of its strata in the Jura mountains.

3. Cretaceous, because the chalks of England and France belong to this period.

In Europe the Triassic formation is more distinctly separated from the Jurassic than in America, and they are, therefore, spoken of in this country as the Jura-Trias, or Triasso-Jurassic.

1357. Triassic.—See Jüra-Trias.

1358. Jurassic.—In the Jurassic are reproduced on a large scale the conditions favorable to luxuriant growth of

plants and for their accumulation and preservation in the form of coal. To this period belong the coal fields of Kimmeridge (the Kim coal) in England; the Moorland coal of Yorkshire, England, and the coal of Brora, Sutherlandshire, Scotland.

1359. Jura-Trias, or Triasso-Jurassic.—To the Jurassic, or Triassic, belong the coals of North Carolina, or Dan river, Eastern Virginia, or Richmond and Piedmont, and some of the coal fields of China, India, and Australia. These coal measures have a general structure similar to those of the Carboniferous, consisting of alternate beds of sand and clay, and occasional limestones containing the seams of coal, and also beds of clay iron-stone. Underclay with stumps and roots, and leaf impressions, innumerable, are found in the roof shales. It is, therefore, logical to conclude that the manner of accumulation was the same as with those in the Carboniferous Age.

1360. Specimen fossils of the Triassic age are shown in Fig. 383. They are:

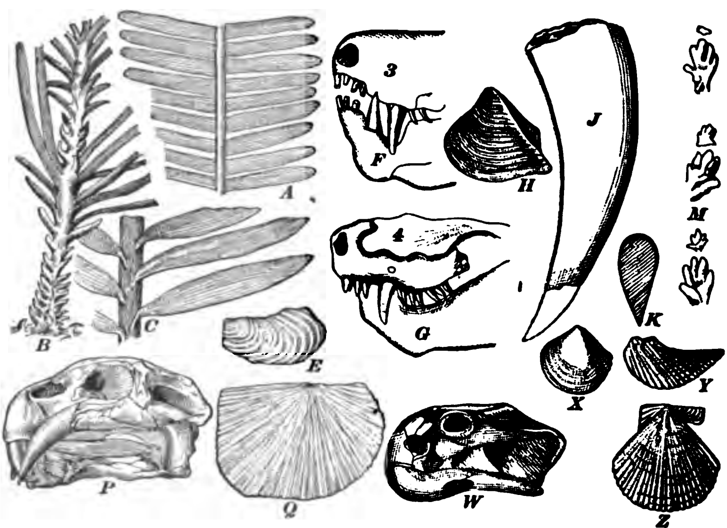


FIG. 383.

A, pterophyllum jegeri, a cycad; *B*, voltzia heterophylla,

a conifer; *C*, podozamites emmonsi, a cycad; *E*, avicula socialis; F_3 and G_4, lycosaurus; *H*, myophoria lineata; *J*, *K*, bathygnathus borealis; *M*, tracks of a cheirotherium, a labyrinthodont; *P*, dicynodon lacerticeps; *Q*, daonella lommelli; *W*, oudenodon bainii; *X*, cardium rheticum; *Y*, avicula contorta; *Z*, pecten valoniensis.

1361. Specimen fossils of the Jurassic age are shown in Fig. 384. Their names are:

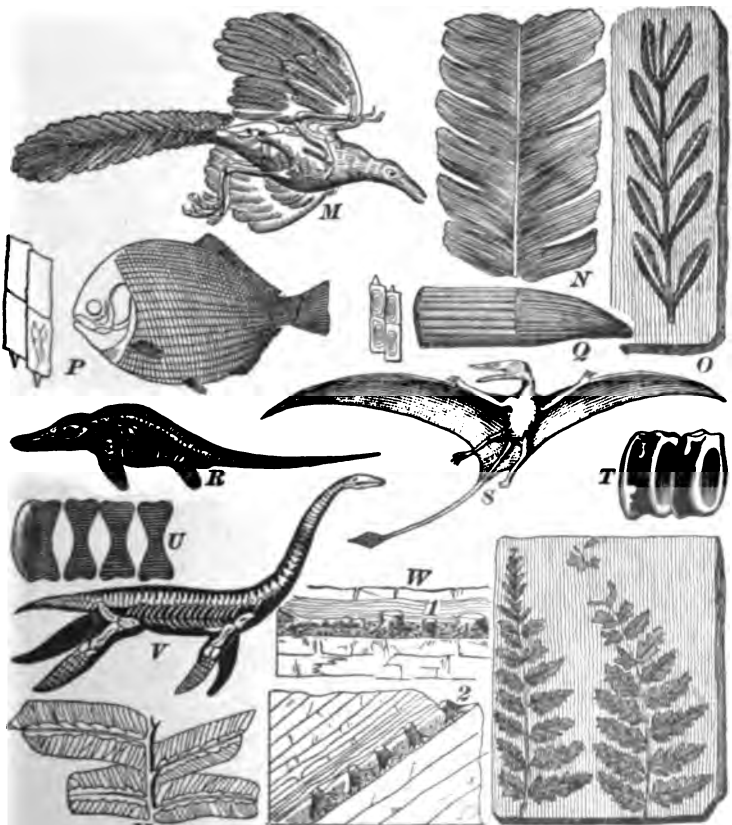


FIG. 384.

M, archeopteryx macrura; *N*, pterophyllum comptum,

a cycad; *O*, pachypteris lanceolata; *P*, *ganoid*, tetragonolepis, restored, and scales of the same; *Q*, tooth of ichthyosaurus; *R*, ichthyosaurus communis; *S*, rhamphorhynchus phollurus; *T*, *U*, vertebræ of ichthyosaurus; *V*, plesiosaurus dolichodeirus; *W*, *Z*, *1* and *2*, show fossil soils of forest grounds with erect stumps and ramifying roots *in situ*; *X*, coniopteris murrayana; *Y*, hemitelites brownii, a fern.

1362. Specimen fossils of the Jura-Triassic age are shown in Fig. 385. They are as follows:

A, walchia diffusus; *B*, pecopteris falcatus; *C*, alethopteris whitneyi; *D*, otozamites macombii; *E*, zamites occidentalis; *F*, branch of conifer (brachyphyllum); *G*, neuropteris; *H*, branch of conifer; *I*, neuropteris linefolia; *J*, podozamites emmonsi; *K*, podozamites crassifolia; *M*, fruit of conifer; *N*, teniopteris elegans.

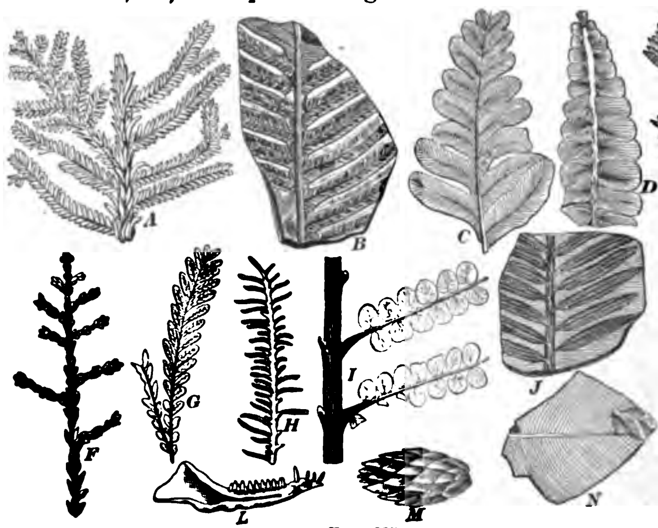


Fig. 385.

1363. Cretaceous.—The chalk (a soft, white, pure carbonate of lime) of England and France belongs to the Cretaceous period. The chalk has scattered through it in layers, or irregularly, nodules of pure flint. With this exception, the Cretaceous period consists of sands, clays, and limestone in much the same condition as in the other

formations, but, as a whole, they are less frequently metamorphic than the older rocks.

By referring to the Geological Chart for North America, it will be seen that the Cretaceous is divided into Upper and Lower, but it might conveniently be subdivided into Upper, Middle, and Lower. These subdivisions are local. In Europe, nearly everywhere, the Tertiary is unconformable on the Cretaceous, but in America, there is a transition period between the Cretaceous and Tertiary, called the Laramie; sometimes it is included in the Upper Cretaceous.

1364. Laramie-Cretaceous.—This, excepting the Carboniferous Age, contains the largest coal field in the United States and Canada.

1. Plateau Coal Field.—This valuable field covers most of the Laramie plains in Montana and Wyoming, and stretches into Utah. The area must be very great.

2. Coal Field of the Plains.—Of great area in Dakota, and extending into Assiniboia, Saskatchewan, Alberta, and Athabasca in British America. Area, enormous.

3. New Mexico Coal Field.

4. Kansas-Colorado Coal Field.—A large coal field covering the greater portion of Western Kansas and Eastern Colorado.

5. Pacific Coal Field.—This is comprised of the Seattle, Carbon Hill, and Bellingham Bay areas in Washington.

6. British Columbia Coal Field.—The Nanaimo coal areas of Vancouver's Island.

7. Californian Coal Field.—Monte Diablo and Corral Hollow areas in California.

8. The *Coahuila Coal Field.—Including all the coal areas on the Sabinas River, at Fuente and San Tomas, in the State of Coahuila, Mexico, and Eagle Pass, etc., Texas.

*There is a doubt as to whether the Coahuila coal is Laramie-Cretaceous or Carboniferous.

Many of these coals are in no way inferior to the Carboniferous coals.

The Coahuila and Colorada (Crested Butte and El Moro) are good coking coals.

These fields produce anthracite, bituminous, high-grade lignites, and lignites.

1365. In Fig. 386 are shown specimens of Cretaceous fossils. They are: *A*, restoration of ichthyornis victor (after Marsh); *B*, hadrosaurus (restored by Hawkins); *C*, belemnites impressus (after Gabb); *D*, salix proteafolia; *E*,

FIG. 386.

liquidambar integrifolium; *F*, protophyllum quadratum; *G*, laurus nebrascensis; *H*, sassafras araliopsis; *I*, fagus polyclada.

As there are no coal formations of any value above the Laramie, it is scarcely within the province of Economic Geology of Coal to go into the more recent ages; but the leading fossils found in these recent formations are illustrated, as they are very useful as a guide to the prospector.

1366. Specimens of Tertiary fossils are shown in Fig. 387. They are as follows:

A, head of a sivatherium giganteum; *B*, tooth of zeuglo-

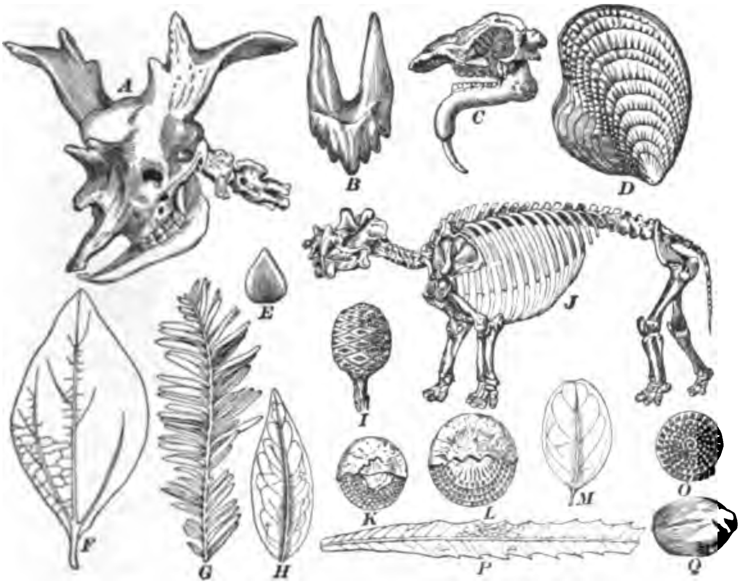


FIG. 387.

don cetoides; *C*, head of dinotherium giganteum; *D*, ostrea selleformis; *E*, fagus ferruginea, nut; *F*, cinnamomum mississippiense; *G*, leaf of sequoia langsdorfii; *H*, andromeda vaccinifoliæ affinis; *I*, fruit of sequoia langsdorfii; *J*, tinoceras ingens; *K*, *L*, *O*, nummulina levigata; *M*, quercus crassinervis; *P*, quercus saffordi; *Q*, carpolithes irregularis.

1367. Specimens of Quaternary fossils are shown in Fig. 388. They are:

A, mammoth (elephas primigenius), skeleton; *B*, tooth of

mastodon americanus; *C*, mastodon americanus; *D*, mega-

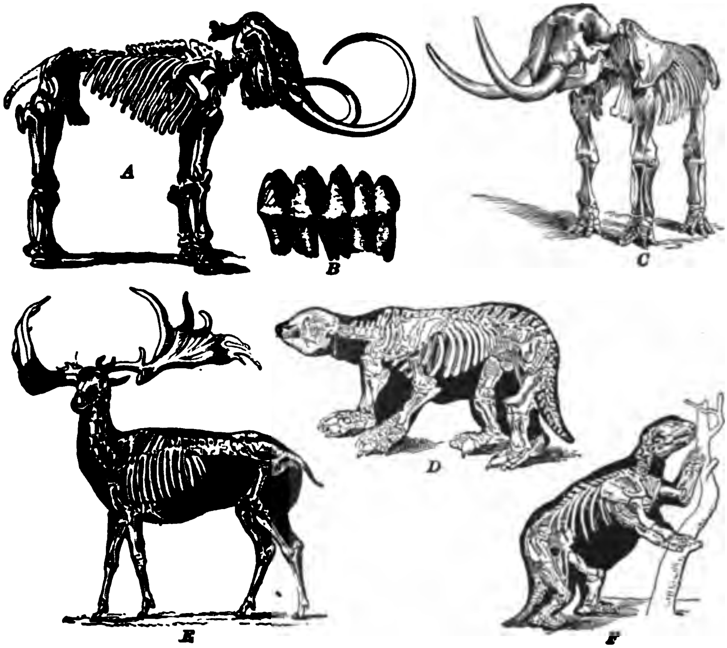


FIG. 888.

therium cuvieri; *E*, Irish elk (cervus megaceros); *F*, mylodon robustus.

GENERAL INFORMATION.

COAL SEAMS.

1368. Thickness of Coal Seams.—Coal seams vary in thickness from a *fraction of an inch* to 80 or 100 feet. A seam can scarcely be said to be workable if less than 18 inches. A pure simple seam is seldom more than 8 or 10 feet thick. Mammoth seams in the south of France and in the anthracite region of Pennsylvania are produced by the running together of several smaller seams, by the thinning out of the interstratified shales, etc. In these mammoth seams there is from 20% to 40% of shale and worthless Carboniferous matter.

1369. Number and Aggregate Thickness.—The strata, including the coal seams in a single coal field, are

repeated many times. A section of the South Joggins coal field, Nova Scotia, shows eighty-one coal seams, but only a few are workable. In Westphalia, Germany, there are 117 seams. The aggregate thickness of all the seams in

Lancashire is 150 feet.
Pottsville, Pa., is 113 feet.
Western Coal Fields is 75 feet.
Westphalia is 274 feet.
Mons, France, is 250 feet.

The great anthracite region of Pennsylvania is largely Lower Carboniferous or lower coal measures. However, in a deep trough in the otherwise nearly horizontal outspread of Catskill formation, the coal measures of Carbondale, Scranton, and Wilkes-Barre have been preserved. They cross Luzerne County so deep in this trough that it has retained not only the *lower* and *middle*, but the upper coal beds, above the Pittsburg bed, and even a remnant of still higher rocks (containing Permian fossils).

The greatest development of the lower coal is in Pennsylvania, and of the upper in the States further west. The highest beds of the series appear to occur west of the Mississippi, in Kansas, where they merge into the Permian.

The following is a section (by J. P. Lesley) of that part above the Pittsburg bed (see Art. **1342**) in Waynesburg, Green County, Pa.:

		Feet.
1.	Shale, brown, ferruginous	30
2.	Sandstone, gray and slaty	25
3.	Shale, yellow and brown	20
4.	Limestone—the great limestone south of Pittsburg (including two coal beds, 2½ feet and 1 foot)	70
5.	Shale and sandstone	17
6.	Limestone	1
7.	Shale and sandstone	40
8.	Coal	6
9.	Shale, brown and yellow	10
10.	Sandstone, coarse brown	35

		Feet.
11.	Shale	7
12.	Coal	$1\frac{1}{2}$
13.	Limestone 4 feet, shale 4, limestone 4, shale 3	15
14.	Shale 10 feet, sandstone 20, shale 10	40
15.	Coal	1
16.	Sandstone (at Waynesburg) with 4 ft. of shale	24

The Eastern Interior Coal Field and the Western Interior Area may be regarded as one, having been separated by denudation, and, like the Appalachian Coal Field, may have been a hollow surrounded by high lands.

1370. Climate.—Le Conte says: "The climate of the coal period was undoubtedly characterized by greater warmth, humidity, uniformity, and a more highly carbonated condition of the atmosphere than now. Most of these characteristics, if not all, are indicated by the nature of the vegetation.

"(1) The warmth is shown by the existence of a tropical vegetation. Of the present flora of Great Britain, about one thirty-fifth are ferns, and none of these tree ferns. Of the coal flora of Great Britain, about one-half were ferns, and many of these tree ferns. At present, in all Europe, there are not more than sixty known species of ferns. In European coal measures, there are 350 (Lesquereux) species, and these are certainly but a fraction of the actual number then existing. That this indicates a tropical climate is shown by the fact that out of 1,500 species of living ferns known twenty years ago, 1,200, or four-fifths, were tropical species. The number of known living ferns is about 3,000 (Nature, Aug., 1876), but the proportion of tropical species is still probably the same. Even in the tropics, however, the proportion of ferns is far less than in Great Britain during the coal period.

"Again, tree ferns, arborescent lycopods, cycads, and Araucarian conifers are now wholly confined to tropical or

sub-tropical regions. The prevalence of these tropical families and their immense size, compared with their congeners of the present day, would seem to indicate not only tropical but ultra-tropical conditions. And these conditions prevailed, not only in the United States and Europe, but northward into polar regions, for in Melville Island, 75° north latitude, and Spitzbergen, 77° 33′ north latitude, have been found coal strata containing tree ferns, gigantic lycopods, calamites, etc.

"(2) The humidity is indicated by the fact that tree ferns and arborescent lycopods are most abundant now on islands in the midst of the ocean, and, further, by the great extent of the coal swamps, and, perhaps, also by the general succulence of, or the predominance of, cellular tissue in the plants of that period.

"(3) The uniformity is proved by the great resemblance and often identity of the species in the most widely separated regions. According to Lesquereux, out of 434 American and 440 European species, 176 are common, and the remainder far less diverse in character than the species of the two floras at present. Again, in all latitudes from the tropics to 75° north latitude, coal species are extremely similar. Such uniformity of vegetation shows a remarkable uniformity of climate. From the earliest times until the present, there has been probably a gradual evolution of continents—a gradual differentiation of land and water, a consequent differentiation of climates, and a corresponding differentiation of faunas and floras.

"(4) The carbonated condition of the atmosphere is proved by the large quantity of carbon laid up in the form of coal, the whole of which was withdrawn from the atmosphere in the form of carbonic acid. It is also indicated by the nature and the luxuriance of the vegetation. The proportion of carbonic acid in the atmosphere is now about $\frac{1}{20}$ per cent. ($\frac{1}{2000}$). Now, since carbonic acid is the necessary food of plants, it is natural to expect that, up to a certain limit, the increase of atmospheric carbonic acid would increase the luxuriance of vegetation.

"We may, therefore, picture to ourselves the climate of this period as warm, moist, uniform, stagnant (for currents of air are determined by difference of temperature), and stifling from the abundance of carbonic acid. Such physical conditions are extremely favorable to vegetation, but unfavorable to the higher forms of animal life."

1371. Plants and Genera.—In European coal beds, much the same genera of plants are found as in American coal beds, and very many of the species are identical. In this respect, the animal and vegetable kingdoms are in strong contrast, for the species of animals common to the two continents have always been few.

VARIETIES OF COAL.

1372. Dana classes the varieties of coal as follows:

1. **Anthracite.** Hardness, 2 to 2.5. Specific gravity, 1.32 to 1.7, Pennsylvania; 1.81, Rhode Island; 1.26 to 1.36, South Wales. Luster bright, often sub-metallic, iron-black, and frequently iridescent. Fracture conchoidal. Volatile matter after drying, 3 to 6 per cent. Burns with a feeble flame of a pale color. The anthracites of Pennsylvania contain ordinarily 85 to 93 per cent. of carbon; those of South Wales, 88 to 95; of France, 80 to 83; of Saxony, 81; of Southern Russia, sometimes 94 per cent. Anthracite graduates into bituminous coal, becoming less hard, and containing more volatile matter; and an intermediate variety is called "free burning anthracite."

1373. 2. **Bituminous Coals.**—Under the head of bituminous coals a number of kinds are included which differ strikingly in the action of heat, and which, therefore, are of unlike constitution. They have the common characteristic of burning in the fire with a yellow, smoky flame, and giving out on distillation hydro-carbon oils or tar, and, hence, the name bituminous. The ordinary bituminous coals contain from 5 to 15 per cent. (rarely 16 or 17) of oxygen (ash included); while the so-called brown coal, or lignite, contains from 20 to 36 per cent. after the expulsion, at 212° Fahr.,

of 15 to 36 per cent. of water. The amount of hydrogen in each is from 4 to 7 per cent. Both have a usually bright, pitchy, greasy luster (whence often called Pechkohle in Germany), a firm, compact texture, are rather fragile compared with anthracite, and have a specific gravity of 1.14 to 1.40. The brown coals have often a brownish-black color, whence the name, and more oxygen, but in these respects and others they shade into ordinary bituminous coals. The ordinary bituminous coal of Pennsylvania has a specific gravity of 1.26 to 1.37; of Newcastle, England, 1.27; of Scotland, 1.27 to 1.32; of France, 1.2 to 1.33; of Belgium, 1.27 to 1.3. The most prominent kinds are the following:

1374. 3. **Caking Coal.**—A bituminous coal which softens and becomes pasty, or semi-viscid, in the fire. This softening takes place at the temperature of incipient decomposition, and is attended with the escape of bubbles of gas. On increasing the heat, the volatile products, which result from the ultimate decomposition of the softened mass, are driven off, and a coherent, grayish-black, cellular, or fritted mass (coke) is left. Amount of coke left (or part not volatile) varies from 50 to 85 per cent. Byerite is from Middle Park, Colorado.

1375. 4. **Non-Caking Coal.**—Like the preceding in all external characters, and often in ultimate composition; but burning freely without softening or any appearance of incipient fusion.

1376. 5. **Cannel Coal** (Parrot Coal).—A variety of bituminous coal, and often caking; but differing from the preceding in texture and to some extent in composition, as shown by its products on distillation. It is compact, with little or no luster, and without any appearance of a banded structure; and it breaks with a conchoidal fracture and smooth surfaces; color, dull black or grayish-black. On distillation it affords, after drying, 40 to 66 per cent. of volatile matter, and the material volatilized includes a large proportion of burning and lubricating oils, much larger

than the above kinds of bituminous coal; whence it is extensively used for the manufacture of such oils. It graduates into oil-producing coaly shales, the more compact of which it much resembles.

1377. 6. **Torbanite.**—A variety of cannel coal of a dark brown color, yellowish streak, without luster, having a sub-conchoidal fracture; hardness, 2.25; specific gravity, 1.17 to 1.2. Yields over 60 per cent. of volatile matter, and is used for the production of burning and lubricating oils, paraffin, and illuminating gas. It is found at Torbane Hill, near Bathgate, in Linlithgowshire, Scotland. It is also called Boghead cannel.

1378. 7. **Brown Coal** (Lignite).—The prominent characteristics of brown coal have already been mentioned. They are non-caking, but afford a large proportion of volatile matter. They are sometimes pitch-black, but often rather dull and brownish-black. Specific gravity, 1.15 to 1.3; sometimes higher from impurities. It is occasionally somewhat lamellar in structure. Brown coal is often called lignite. But this term is sometimes restricted to masses of coal which still retain the form of the original wood. Jet is a black variety of brown coal, compact in texture, and taking a good polish, whence its use in jewelry.

1379. Composition.—Most mineral coal consists mainly, as the best chemists now hold, of oxygenated hydro-carbons. Besides oxygenated hydro-carbons, there may also be present simple hydro-carbons (that is, containing no oxygen).

Sulphur is present in nearly all coals. It is supposed to be usually combined with iron, and when the coal affords a red ash on burning, there is reason for believing this true. But Percy mentions a coal from New Zealand which gave a peculiarly white ash, although containing 2 to 3 per cent. of sulphur, a fact showing that it is present, not as a sulphide of iron, but as a constituent of an organic compound. The discovery by Church of a resin containing sulphur (Tasmanite), gives reason for inferring that it may exist in this

coal in that state, although its presence as a constituent of other organic compounds is quite possible.

1380. The following table refers to the coals found in the United States:

	Fracture of Coal.	Cleat of Coal.
Rhode Island..............	Conchoidal, or shelly.	....
Anthracite region, Pa	Conchoidal, glossy, and lustrous.	Very irregular.
Semi-Anthracite region, Pa.	Irregular and cuboidal.	More regular.
Pittsburg region, Pa.	Clean, bright, even cuboidal.	Remarkably regular, nearly vertical jointing.
Ohio......................	Fairly regular and smooth.	Makes blocky coal.
Indiana	Fairly regular and smooth.	Makes blocky coal.
Illinois.....................	Rough to smooth.	Poorly developed.
Iowa........................	Rugged, irregular.	Hardly any.

VARIETIES OF LIMESTONE.

1381. The following in substance is given by Dana:

Massive Limestone.—Compact uncrystalline limestone of dull gray, bluish gray, brownish, and black colors; in texture, varying from earthy to compact semi-crystalline.

It consists essentially of calcite or carbonate of calcium, but is often impure with clay or sand.

When burned, limestone becomes quicklime through loss of carbonic acid; and, at the same time, all carbonaceous materials are burned out, and the color, when it is owing solely to these, becomes white.

Magnesian limestone, dolomite, consists of calcium and magnesium, but not distinguishable in color or texture from ordinary limestone. The amount of magnesian carbonate present varies from a few per cent. to that in true dolomite which can not be distinguished by the eye from granular

limestone. Much of the common limestone of America is magnesian.

In some limestones, the fossils are magnesian, while the rock is common limestone.

Hydraulic Limestone.—A limestone containing some clay, and affording a quicklime, the cement of which will *set* under water.

Oolyte, or Roe Stone.—Limestone, either magnesian or not, consisting of minute concretionary spherules, and looking like the petrified roe of fish; the name is from the Greek, meaning egg.

Chalk.—A white, earthy limestone easily leaving a trace on a board; composition, the same as that of ordinary limestone.

Marl.—A clay containing a large proportion of lime.

Shale Marl.—Marl consisting largely of shells or fragments of shells.

Shell Limestone, Coral Limestone.—A rock made of shells or corals.

Travertine.—A massive limestone formed by deposition from calcareous springs or streams.

Stalagmite, Stalactite.—Depositions from water trickling through the roofs of limestone caverns, form calcareous cones and cylinders pendent from the roofs, which are called stalactites, and incrustations on the floors, which are called stalagmites.

Granular Limestone (Statuary Marble).—Limestone having crystalline granular texture, white to gray color, often clouded with other colors from impurities; it is a metamorphic rock; it was originally common limestone. All the fossils present were obliterated, except in some cases of partial metamorphism. The varieties are as follows: Statuary marble, ornamental and architectural marble, verd-antique, or ophiolyte, micaceous, tremolitic, graphitic, chloritic, and chondroditic.

GLOSSARY.

1382. *Acrogens.*—Consist of vascular tissue in part and grow upwards; as (1) ferns; (2) lycopods (ground-pine); (3) equisetæ; and include many genera of trees of the coal period.

Age.—(1) Any great period of time in the history of the earth or the material universe, marked by special phases of physical condition or organic development; as, the Age of Mammals. Called also *era*. (2) One of the minor subdivisions of geological time, a subdivision of the epoch and correspondent to the stage or formation; recommended by the International Geological Congress. See Geological Chart for North America.

Amphibians.—Animals capable of living both on land and in water, like the frog.

Antiseptic.—Opposed to or counteracting decay.

Araucarian.—A genus of fossil trees of the pine family (coniferæ) represented by trunks (often of great size), and closely allied to araucaria, a genus of large evergreen trees of the pine family.

Arborescent.—(1) Having the nature of a tree; tree-like in appearance or size. (2) Branching like a tree.

Articulates.—Consisting (1) of a series of joints or segments; (2) having the legs, when any exist, jointed; (3) having the viscera and nervous cord in the same general cavity; (4) having no *internal* skeleton, as worms, crustaceans, insects.

Brachiopods.—See definition of Foraminifera, and also *22 a*, *22 b*, *23 a*, *23 b*, and *29*, Fig. 374.

Bryozoans.—Moss animals, so named with reference to the moss-like corals they often form. The corals consist of minute cells either in branched, reticulated, or encrusting forms. They are often calcareous; and as such were common in the Silurian Age, and still occur.

Buhrstone (Burrstone).—A cellular but very compact silicious rock from which the best millstones are made.

Calamites.—Fossil plants of the Carboniferous coal formations, having the general form of plants of the modern equisetæ [the horse-tail, or scouring rush, family (see definition of equisetæ)], but sometimes attaining the height of trees and having the stem more or less woody within (*R*, Fig. 381, is a calamite restored).

Cephalopods.—Cuttlefishes. There are two orders of cephalopods; one having external shells and four gills; a second, having sometimes internal shells but no external, and having but two gills. The external shells are distinguished from those of gasteropods (or ordinary univalves) by having, with a rare exception, transverse partitions. They may be either straight or coiled; but with few exceptions they are coiled in a plane instead of being spiral.

Clay Iron-stone.—The ore is generally the carbonate of iron, called siderite (or often spathic iron). It contains as impurity ten to thirty per cent., or more, of silica and other earthy matters, and hence is called clay iron-stone.

Clinometer.—An instrument employed for determining the dip of strata.

Coccospheres.—Supposed shells of minute plants having but one cell.

Columnar.—Columnar structure—structure, as in certain igneous rocks, showing a tendency to cleave into columns. Columnar appearance—like the shaft of a column.

Congener.—An organism that belongs to the same genus as another, or to one closely related; a member of the same stock, group, kind, or species with another.

Conifers.—A plant which has a bark and grows by an addition annually to the exterior of the wood, between the wood and the bark, and hence the wood shows, in a transverse section, rings of growth, each forming a single year. Examples are the pine, spruce, hemlock, etc.

Correlative.—Mutually involving or implying one another.

Crustaceans.—Animals whose bodies are protected by shells, as crabs, lobsters, shrimps.

Crystalline.—Composed of angular grains or particles more or less crystallized in place.

Culmination.—The highest point, condition, or degree of achievement; as the culmination of life.

Cycads.—A family of palm-like or fern-like plants with unbranched stem bearing a crown of feather-like leaves, rolled inwards from the apex in a coil.

The Cycadaceæ embrace 9 genera and 75 species, chiefly of the Southern Hemisphere.

Débris.—An aggregation of detached fragments of rocks, whether *in situ* at the base of its original cliff, or heaped up after transportation (drift in part).

Delta.—An alluvial deposit formed at the mouth of a river; so called from its frequent resemblance to the fourth letter delta (Δ) of the Greek alphabet.

Detritus.—(1) Loose fragments or particles of rock, whether angular or water-worn, especially the latter. (2) A mass of disintegrated material of any kind; rubbish; waste.

Dominant.—Conspicuously prominent in point of numbers.

Dyke.—A mass of igneous rock filling a fissure in other rocks into which it has been intruded.

Echinoderms.—Animals having their exterior more or less calcareous and often furnished with spines; and having distinct nervous and respiratory system and intestines, as starfish, crinoids, etc.

Encrinites or Crinidea.—Having a regular radiate structure, and arms proceeding from the margin of the disk; also, a stem consisting of calcareous disks, by means of which, when alive, they are attached to the sea bottom, or some support, so that they stand in the water and spread their rays like flowers, the mouth being at the center of the flower.

Epoch.—The chronological subdivision of geological history of the third order; as the Hamilton *epoch*.

The corresponding stratigraphic division proposed by the

International Congress of Geologists is the *series;* that recognized by the U. S. Geological Survey is the *formation.* Compare with *group*, and see Geological Chart for North America.

Equisetæ.—Horse-tail family—a tribe of plants as represented by calamites.

Era.—The highest chronological division of geological history in the scheme proposed by the International Congress of Geologists and that of the U. S. Geological Survey; as the Paleozoic *era.*

Erosion.—The wearing away of rocks, chiefly by running water, but also by shore waves, glaciers, and winds.

Ferruginous.—Containing or having the nature of iron.

Flexed.—Bent, curved, or bowed.

Foraminifera.—A family of very minute shell animals, consisting of one or more series of chambers united by a small perforation or foramen. Examples: protozoans, radiates, mollusks. These characteristic species are subdivided through a wide range; for instance, the rhizopods are protozoans; polyps are radiates; brachiopods are mollusks.

Ganoids.—Fishes having the body covered with shining bony scales or plates, as in the garpike of existing waters, and hence named *Ganoid* by Agassiz, from the Greek word meaning *shining.*

Gasteropods.—Animals of the snail and slug species.

Genera.—Genus, race, kind, sort.

Glaciers.—Tongues or rivers of ice. Ordinary glaciers are accumulations of ice, descending along valleys from snow-covered elevations. They are ice-streams 200 to 5,000 feet deep, or more, fed by the snows and frozen mist of regions above the limits of perpetual frost. They extend 4,000 to 7,500 feet below the snow line (limit of perpetual snow) because they have such magnitude that the heat of the summer season is not sufficient to melt them an appreciable amount.

Gneiss.—A crystallized rock composed of feldspar, quartz,

and mica intimately intermixed, and having the mica foliated or disposed in parallel planes, producing a moderate tendency to cleavage into thick slabs; thus distinguished from *granite*.

Graphite.—This is simply carbon, neither lead nor iron occurring in the pure mineral. It is often called plumbago and black lead (the material of lead pencils), and looks like a metallic substance.

Group.—In stratigraphical classification of stratified rocks, the division next below the system or series: (1) In general usage, the chief subdivision of the system, in the ordinary application of that word, as the Chemung *group* of the Devonian system. (2) In the official usage of the U. S. Geological Survey, one of the chief subdivisions of a system (*system* being applied to the grander divisions of geological history), based mainly upon paleontological distinctions, but also upon structural separateness, as the Devonian *group* of the Paleozoic system (age). Under this usage *formation* replaces the word *group* in its more common application. (3) In the scheme proposed by the International Congress of Geologists, the highest stratigraphic division, corresponding with *era*, the highest chronological division.

Gulf Stream.—A great ocean current flowing from the Gulf of Mexico northward nearly parallel to the Atlantic coast of the United States, and turning eastward off Nantucket Island, its average rate being about two miles per hour. It plays an important part in ameliorating the climate of Great Britain and Norway. The similar Japan current, or *Kuro-Shiwo*, which gives a warm, moist climate to the lower Alaskan coast, is sometimes called the *Gulf Stream* of the Pacific.

Heteropod.—One of the family of gasteropods.

In situ.—In its original or proper site or position.

Invertebrate.—Not having a backbone.

Laccolite.— A mass of intrusive lava, which spreads out

laterally, at one or more points between strata, in lenticular

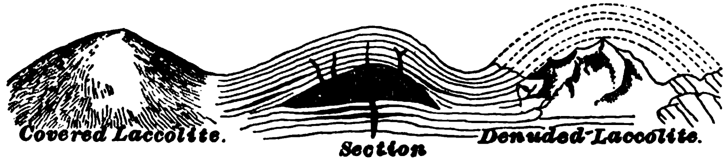


FIG. 389.

forms, lifting the overlying rocks into domes. (Fig. 389.)

Lamellar.—Composed of thin layers, plates, scales, deposited in layers like the leaves of a book.

Lamellibranchs (leaf-gills).—These belong to the mollusks. The valves of the lamellibranchs are right and left, while those of the brachiopods are upper and lower.

Silurian lamellibranchs are shown as Nos. *24*, *25*, *26*, *27*, and *28*, Fig. 374.

Lepidodendron.—A genus of fossil trees of the Devonian and Carboniferous Ages, having the exterior marked with scars (see *K*, Fig. 381) produced by the separation of the leaf stalks.

Lithostrotian.—Large corals.

Lycopod.—A flowerless plant of the coal period. An acrogen.

Mammals.—Species suckling their young, a characteristic peculiar to the highest branch of the animal kingdom; breathing by lungs; having a heart of four cavities; as ordinary quadrupeds, with whales and seals.

Marl.—A clay containing a large proportion of carbonate of lime—sometimes 40 to 50 per cent. If the marl consists largely of shells or fragments of shells, it is called *shale marl.* Marl is used as a fertilizer, and other beds of clay or sand that can be so used are often in a popular way called *marl.* The "green sand" of New Jersey is of this kind. This green sand owes its peculiarities to a green silicate of iron and potash, which forms the bulk of it, and sometimes even 90 per cent., the rest being ordinary sand.

Mesa (pronounced masa).—A high, broad, flat table-land,

bounded, at least on one side, by a steep cliff rising from lower land; a plateau; terrace; flat-topped hill.

Mica Schist.—Consists mainly of quartz and mica, and some other minerals, and divides readily into slabs.

Olenellus.—See fossil No. *37*, Fig. 374.

Organism.—A body composed of different organs or parts performing special functions that are mutually dependent and essential to life; an animal or plant.

Pentremites.—A genus of crinoids. (See *F* and *G*, Fig. 380.)

Period.—One of the larger divisions of geological time; as the Jurassic *period.* The geological application of the word varies with different authors. In the scheme of nomenclature proposed by the International Geological Congress, *period* is the chronological term of the second order, to which *system* is the corresponding stratigraphic term; as Silurian *period* or system. In the scheme of the United States Geological Survey, *period* has the same rank, but its corresponding stratigraphic term is *group.*

Permo-Carboniferous.—That epoch of the later Carboniferous formations called Permian.

Placoids.—Any fishes having plate-like scales similar to those on the shark.

Polyps.—Marine animals with many feet or tentacles.

Prehistoric Eras.—Eras previous to even the most imperfect record of the history of the earth.

Prismatic.—Shaped like a prism.

Prism.—A form consisting of three or more intersecting planes whose intersections are parallel and vertical and whose bases have three or more sides.

Protozoans.—See definition of Foraminifera. Also Nos. *61*, *63*, *64*, and *65*, Fig. 374.

Pteropods.—Small animals which swim by means of wing-like appendages.

Radiates.—Having a *radiate* structure, like a flower, internally as well as externally; i. e., having similar parts

or organs repeated around a vertical axis. The animals have a mouth and stomach for eating and digesting.

Shingle.—A mass of loose rounded pebbles, coarser than ordinary gravel.

Sigillaria.—A genus of fossil trees principally found in the coal formations—so named from the seal-like leaf scars in vertical rows on the surface. (See *M* and *P*, Fig. 381.)

Silica.—Silicon, after oxygen, is the most abundant element, and constitutes at least one-fourth of the earth's crust. It is unknown in nature in the pure state; but combined with oxygen, and thus forming *silica*, it is common everywhere. This *silica* is an acid, although tasteless; and its combinations with alumina, magnesia, lime, and other bases (called *silicates*), along with quartz, are the principal constituents of all rocks except limestones.

Spathic Iron Ore.—See definition of clay iron-stone. Carbonate of iron is the ore of iron called *siderite* or *spathic iron.*

Stigmaria.—The generic name of certain forking roots, common in the older coal measures, supposed to belong to various species of sigillaria, etc. (See footnote, Art. **1354.**)

Talc Schist.—Consists of quartz and talc.

Trap.—A dark colored eruptive rock frequently found in columnar structure, as certain basalts.

Vertebrates.—Animals, including men, mammals, birds, reptiles, and fishes which have a backbone, or vertebral column, containing the spinal marrow.

Vice versa.—The order or relation being reversed.

Zoophytes.—A general term, applied to simple polyps, and compound individuals consisting of many polyps united together, and the polyps resemble flowers in form.

The term formerly included sponges and corallines in addition to the above.

PROSPECTING FOR COAL AND LOCATION OF OPENINGS.

PROSPECTING.

PRELIMINARY EXAMINATIONS.

1383. Prospecting is a practical application of geological knowledge for the purpose of determining whether coal or any other useful mineral may be found in any particular locality.

In prospecting for coal a *general* knowledge of all formations, and a *special* knowledge of coal-bearing formations, are required.

1384. Preliminary Considerations.—Before beginning to prospect extensively the following points should be considered: 1. Is the location of the tract such as to enable shipments to be made in an economical manner; that is, are there rail or water facilities immediately available, or, if not, is there a reasonable prospect of rail facilities in the near future? 2. What competition must be met in available markets, and what advantage, if any, will coal from the tract in question have in those markets? 3. Is there an abundance of labor near the tract, or can sufficient labor be brought there from other fields? If these questions, more particularly the first two, can be answered satisfactorily, the work of prospecting should begin.

1385. Preliminary Work.—Searching for coal in an unprospected region should first be done in a general way, and secondly in a more particular manner. The prospector should first go over the ground, carefully noting all

prominent features, and gather all the general information possible regarding exposed rocks. If he finds evidence of rocks of the coal-bearing periods, either on the tract, or on adjacent tracts, he should decide on the best location of points from which a general approximate survey of the tract may be triangulated.

1386. Approximate Survey.—When no fairly reliable map of the region to be prospected is obtainable, one must be constructed. The survey for such a map can be most easily made by triangulation. To make a survey by triangulation the prospector must accurately measure as long and level a straight base line as possible. From each end of the base line, with his pocket compass, he must take a bearing to one of the points selected in the preliminary examination. He then has a triangle with two angles and the length of the included side, and he can readily calculate the value of the other angle and the lengths of the other two sides. The point of intersection of the two lines from the ends of the base line will mark the position of the object sighted to on the map. When the sights are taken to the first point, the prospector has *three* base lines on which to construct other imaginary triangles, completely covering the entire tract and as much adjacent territory as he wishes. Care should be taken to number each point from which a bearing is taken, and to use the same number in designating it, each time a sight is taken to it or from it. Having in this manner located all the prominent points, it is an easy matter to fill in the topography in an approximate manner. The map thus formed, though not quite accurate, will answer the purpose of the prospector.

1387. To make clear this method of triangulation, Fig. 390 shows an example of the work. In this instance the line *1* to *2* is assumed as the base line first measured, and its course due E and W, and its length as 600 ft. Then from the point *1* a bearing of N 50° E is taken to point *3*, and N 10° W to point *4*. Then from point *2* a bearing N 40° W to *3*. Then from *3* a bearing S 80° W to *4*. These bear-

ings plotted on the map will show the relative positions of points *1*, *2*, *3*, and *4*. Any number of other points may be located from any two of these. Care should be taken to secure sights from two points that will bring the angle of intersection between 25° and 150°, because with angles below 25° or over 150°, it is difficult to determine, on paper, the exact position of the intersection of the imaginary lines which marks the point sighted to.

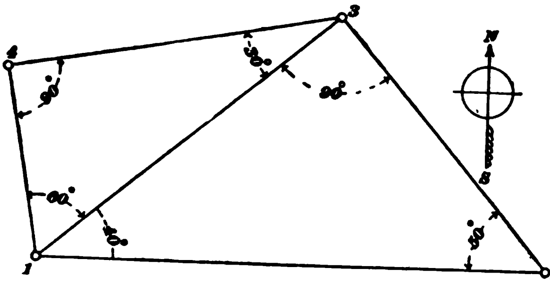


FIG. 390.

If it is desired to know the length of any of the bearings besides the base line, for the purpose of checking the plotting or for any other purpose, the following rule will be found convenient:

$$\left\{\begin{matrix}\text{Sine of the}\\ \text{angle opposite}\\ \text{the given side}\end{matrix}\right\} : \left\{\begin{matrix}\text{Sine of angle}\\ \text{opposite}\\ \text{required side}\end{matrix}\right\} :: \left\{\begin{matrix}\text{Length}\\ \text{of given}\\ \text{side}\end{matrix}\right\} : \left\{\begin{matrix}\text{Length of}\\ \text{required}\\ \text{side.}\end{matrix}\right\}$$

For example, if we want to find the length of the line *1* to *3*, we have to work with the two angles of 40° at *1*, and 50° at *2*, and the included side 600 ft. long. As the sum of the three angles of all triangles equals two right angles or 180°, the angle at *3* $= 180° - (40° + 50°) = 90°$.

Then, $\sin 90° : \sin 50° :: 600 : x$, or $1 : .7660444 :: 600$ ft. : 459.63 ft. = length of line *1* to *3*.

In the same way we may find the length of line *1* to *4* by using the line *1* to *3* as the base of the triangle *1-3-4*.

1388. Keeping Prospecting Notes.—The notes of the triangulation should be neatly recorded, together with all other data collected while making the triangulations, in a substantially bound note book. The rough or preliminary

map should be on as large a scale as is convenient. Thus, for a tract of land of two miles square, a scale of 400 ft. per inch would be as large a map as could be conveniently used in the field. For larger tracts a much smaller scale is advisable. This scale is so small that to make notes directly on the map, in the field, requires great neatness and care on the part of the prospector, and also the use of conventional signs to designate certain features, so as to prevent the confusion and illegibility of written notes. Fig. 391 shows a number of conventional signs most frequently used by prospectors.

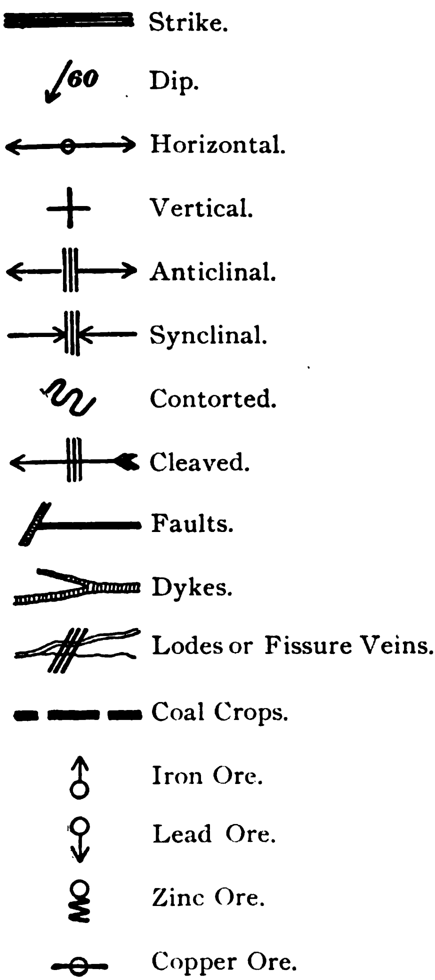


FIG. 391.

1389. Object of First Examination.—The first general examination of a tract is to determine the *character* of the rock beds. Their extent may be shown, approximately, on the map. Every care must be taken to determine rightly the relative ages of the beds, for on this the results of the prospect almost wholly depend. The means by which the relative ages may be determined have been described in Economic Geology of Coal.

1390. Evidences of Coal.—The evidence obtained from the examination of the geological formations may be either favorable or unfavorable. If the preliminary survey shows that the rock beds are of the coal-bearing ages, it may be inferred that coal can be found. The presence of ledges of rock of the coal-bearing ages is presumptive evidence that coal can be found in their neighborhood. On the other hand, if the rocks are undoubtedly of other than coal-bearing ages, then there is practically no prospect of finding coal. As was stated in Economic Geology of Coal, coals are sometimes found in the Sub-Carboniferous, Devonian, and even as low down as the Silurian Age, but these are phenomenal cases. The most marked instance of coal being found below the coal measures occurs in France, at Drocourt, in the Pas de Calais. After sinking through the Cretaceous measures, the Devonian rocks were reached at a depth of 414 ft. After sinking in this foundation 544 ft., very disturbed coal measures and beds of coal, which were worked for a considerable time, were found. The shaft was deepened, and at 1,886 ft. a fault was struck. On passing through this fault the ordinary coal measures of the Carboniferous age were reached. In these measures coal, which is now being worked, was found. Evidently the Devonian and first portion of the coal measures met with had been *bent* completely over before the Cretaceous measures were deposited.

1391. The Determination of Coal-Bearing Strata.—The determination of the Carboniferous and later coal-bearing formations is often a matter of great difficulty, requiring long and careful observation. The prospector must never draw hasty conclusions from the absence of coal measures of the Carboniferous or other coal-bearing ages. The outcrop may be covered under more recent formations. (See Fig. 392.)

The general appearance that never deceives the eye in the older formations is not of much use to the prospector in some cases, on account of the readiness with which these

newer and softer rocks yield to the influence of the atmosphere. The cases may be further complicated by the pres-

FIG. 392.

ence of faults. When these complicated conditions exist, the only method of solving the question is by boring.

1392. Second Stage of Search.—When it is fully established that coal exists in a tract, or there is a very strong probability of it existing there, the second stage of the search is begun. It consists of a more thorough search for and closer observation of the rocks, and a thorough inspection of everything that might lead to the position and detection of the outcrop. It requires accurate surveys and maps, in case they have not been accurately made for the preliminary work. These surveys are required for the laying down on paper, in plan and section, of the true extent and position of the rock beds among which the coal seams occur. The prospector should carefully examine every exposed surface, especially "sections," such as may be found in railroad cuts, escarpments, quarries, wells, and banks of streams. A stream also carries mineralogical specimens obtained from places above where they are found. By ascending the stream and examining minutely the pebbles and sand in the bottom and on the sides, and noting where these fragments that indicate coal cease, a clue to the location of the bed of coal may be found. The approximate distance which these specimens have traveled will be indicated by the more or less worn condition of their edges, considered with relation to their hardness. Nodules of carbonate of iron and some

springs of water are indications of coal, both of which deserve attention. Pieces of shale washed clear of earthy matter should be carefully examined for indications of organic remains and vegetable impressions. Some grains of coal will be found in the stream if the coal crops out near it, and sometimes the rain will wash small grains from a considerable distance into the stream. In the latter case small grains, and even larger pieces, will be deposited along the route, by means of which the location of the parent bed may be traced. When fossils are found, great care should be taken in tracing them to their parent bed also.

COAL-MEASURE TOPOGRAPHY.

1393. It was stated in Economic Geology of Coal that all coal-bearing formations consist of alternating beds of coal, shale, sandstone, etc., some of which yield rapidly to the disintegrating influence of the atmosphere. Coal is most affected; therefore, its outcrop should be looked for especially in depressions of the surface. If a depression is found following everywhere the direction of an exposed ridge of sandstone, it will probably be the outcrop of the seam.

The strongest topographical feature which denotes the presence of bituminous coal seams, where the seam lies above the bottom of the valley in hilly or mountainous districts, is easily recognized by any one familiar with the peculiarities of coal-measure topography. It is the terrace or bench* which almost invariably occurs at the outcrop.

1394. Terrace or Bench.—Because every hard stratum will produce a terrace of some kind, it is necessary to have some means of distinguishing a coal terrace from a bench marking the outcrop of some other stratum.

In the bituminous coal regions of Pennsylvania, Tennessee, and other States, where the seams lie in the hills with a very slight dip, the site of a coal bed is nearly always

*A terrace or bench is a flat surface running along a hillside, resembling in shape an old grass-covered roadway.

indicated by springs, whose waters carry iron in solution, which is deposited in yellow films upon the stones and vegetable matter over which they flow. In some parts of the State of Alabama, in the anthracite regions of Pennsylvania, and other places, the beds, being often highly inclined, rarely furnish such an indication of their presence, except in the sharply cut gaps and ravines eroded across the hills in which the coal occurs.

The coal terrace is generally a well-marked topographical feature, but in many localities the site of the outcrop is not marked by any distinct bench or terrace, and surface examinations fail to disclose any important feature. In tracing a coal terrace the breadth is always affected by

1. The thickness of the seam.
2. The dip of the seam.
3. The slope of the ground.

When the bed dips into the hill the bench is broader than when the pitch is in the opposite direction, and when the surface slope is gentle the bench is generally broader than when a steep hillside or contour prevails.

1395. Direction and Strength of Dip.—A good conception of the direction and strength of dip may be obtained by tracing a terrace for some distance and carefully noting its deflections from a straight line, and the relation of those to the contour of the ground. If the variation occasioned by a depression is towards the foot of the hill, the coal dips in the same direction with the slope of the ground, but if it runs in towards the top of the hill the reverse is true.

Having found a terrace which presents the appearance of a coal terrace, search is made on the bench, and also a short distance below the flat, for a positive indication of coal.

1396. Coal Blossom.—The blossom of a seam frequently is found to have slipped, and detached pieces or patches of outcrop blossom may be found at some little distance from the "full blossom," which is the continuity of

the seam. In the case of bituminous coal the blossom is a soft, black, sooty mixture of coal and clay.

Where the blossom has slipped, a prospect trench about two feet wide is advanced by stages into the hillside, as shown in Fig. 393. The trench may be started at any point below the bench where the prospector's judgment may indicate, or it may advantageously be started on the bench's level. If it shows no indication of coal after it has been advanced to the upper side of the bench (see *a*, Fig. 393),

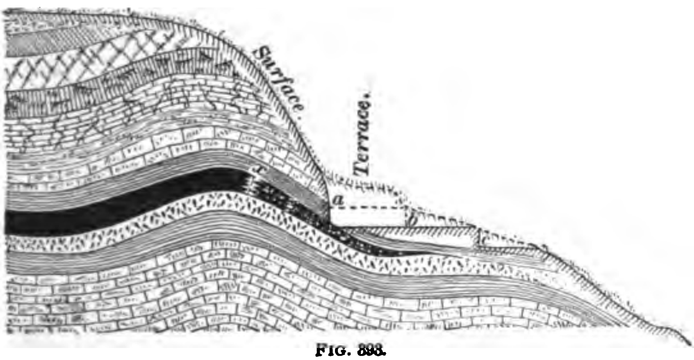


FIG. 393.

a second trench *b* may be started at a lower point and carried up to the place at which the first trench began.

In case the second trench, shown in the figure as *b*, proves barren, a third trench *c* may be started still further down the hill, and be driven up to the beginning of trench *b*. In like manner any number of trenches may be driven. If all the trenches prove barren, any one, as trench *b* for example, may be continued to the point where trench *a* was discontinued. If this trench should find the outcrop, a drift following the crop coal should be driven till the true coal is met at *x*.

It frequently happens that the lowest trench shows the blossom running up, in which case the trench simply follows the indications of coal, which grow stronger until the solid or full face of coal is shown. If only a trace of coal is found by digging these trenches, and the indications or judgment

prompt the prospector to go further into the hillside, the trench is turned into a *drift* by widening it so that a wheelbarrow or a car can be taken in. If these proceedings should give an unsatisfactory result, the trench, or it may be a drift now, should be turned into a prospect shaft and sunk until some trace of coal is reached. If, after sinking a reasonable depth, the result is still negative, it only remains to repeat the experiment at a higher or lower elevation on the hillside at some distance to the right or left of the first trench. The fact of having found no coal, or no trace of coal, is only proof that the material in which the former trench was made has been brought down from the hillside above by a landslide, sweeping before it all traces of the bed. This is very frequently the case with the outcrop where there is a bold escarpment or bluff above it, such as is present in the Cumberland mountains in the form of a conglomerate 20 feet to 80 feet thick, or more, overlying the shales covering the lower coal measures. The shale disintegrated, thus undermining the conglomerate to such an extent that it settled and slid down hill, pushing the strata overlying the coal away down the mountain. Sometimes this slip carried several yards of the seam of coal intact with it, which when first struck by the prospector was very misleading. Where surface indications "give out," a great advantage, which saves much money in locating the outcrop, is secured by running a line of levels from a point where the coal has been opened up to the point where another exposure of the coal is desired. If the coal has a dip, it should be taken into consideration when running this line of levels.

1397. Presumptive Evidence of Coal.—If the surface examination yields no evidence of the presence of coal other than rocks of the Carboniferous or later coal-bearing ages, the existence of coal in the tract is still probable, and boring is resorted to. But it is seldom necessary to bore holes to prove the near existence of coal, for, if the surface examinations are carefully made, unmistakable evidence of its presence will generally be discovered.

It must be distinctly remembered that coals which have an outcrop are now being discussed.

1398. Influence of Slip of Blossom on Thickness of Bed.—The creep, or slipping of the blossom, down hill, when *away from the bed*, will seldom cause the crop to present an exaggerated thickness in a prospect trench or shaft (see *a*, Fig. 394); but when the bed dips with the hill slope, the crop is usually overturned down hill, and the blossom is thus turned over on the outcrop (see *b*, Fig. 394). A prospect shaft sunk through such an overturned outcrop would deceptively indicate the presence of a bed much thicker than the actual measurement of the seam. The prospect shaft should, therefore, be sunk through the entire

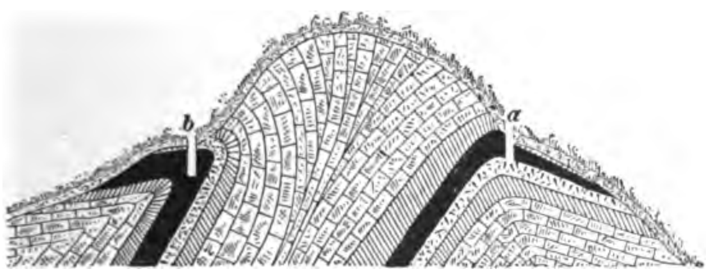


FIG. 394.

thickness of coal until the bottom clay or slate is reached, and then widened out horizontally, or a level should be driven at right angles to it, until the top rock is encountered. When two sets of cleavage planes cross the coal at nearly right angles, or where the outcrop is twisted and contorted by a creep or slide, it may be difficult to distinguish the roof from the floor, on account of the small area of the seam exposed in a prospect opening, and the direction of the dip remains uncertain. The occurrence of stigmaria—the roots of sigillaria—in one of the rock walls of the seam is presumptive evidence that the stratum containing them is the bottom of the seam. But if sigillaria, fern leaves, etc., are found, the rock is probably the roof or top rock, although both of these fossil plant remains may occur in either the roof or bottom of a coal seam.

When the seam has a strong dip and outcrops on a steep hillside, the prospecting shaft may advantageously be replaced by a tunnel.

1399. It may be remarked here that frequently coal diminishes in thickness at the crop so that a 3 or 4 foot seam may diminish to a mere black line at the crop. The reverse is also true, for seams having an outcrop from 3 to 4 feet thick sometimes diminish to a mere black streak between two rocks.

The outcrop of a coal seam may often be detected on the surface, by a line of blackish soft material. The coloring is due to the disintegration of the coal and the deposit of soil mixing with it and covering the coal.

In noting the dips of the various strata exposed at the surface, the prospector must be cautious not to be deceived by false dips. Along the banks of rivers and ravines, the crop of coal in nearly flat areas sometimes has a slight dip inward, continuing only a short distance under the surface, disappearing on reaching normal conditions.

Landslides are to be carefully looked for where the coal crops out on hillsides, as they are liable to give wrong impressions regarding the seam and its dip, etc.

The confusion of strata resulting from plication must be thoroughly understood; otherwise, a wrong conception of the order and number of seams would be obtained. See Economic Geology of Coal.

The undulation of the surface, in many cases, is a true indication of the seam underlying, if the depth is not great, and the distance is not disturbed by throws. The depressions on the surface represent local swamps in the seam almost vertically under the surface depression.

1400. Disturbance of Coal Formations.—In a great many coal fields where a considerable disturbance has taken place, the continuity of the strata is broken by faults in regular succession. (See Fig. 395.) In others the strata may be turned up for a considerable distance at its outer

edges. Thus, we have long slopes ending in long horizontal

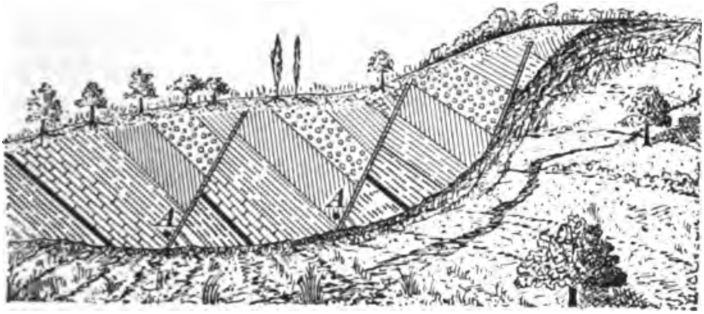


FIG. 395.

gangways, which in turn give way to rising headings or a slope from the opposite side. (See Fig. 396.)

FIG. 396.

1401. Oblique Lamination.—In measuring the dip care must be exercised that oblique lamination, cleavages, or other indications of cross-fracture, and layers displaced by the growing roots of trees, are not mistaken for the true dip of the seam.

1402. True Dip.—While studying the rock bed, the true dip must be carefully determined. There is a great advantage in being able to get a full view of a bed of rocks, inasmuch as the true position of any one of these rocks, when met singly, as well as the position and thickness of the others, if they are not exposed, may be inferred. Every change of the dip deserves attention regarding amount, direction, etc. Such change may be only local, or superficial, instead of belonging to the great and regular bending of the rock. When one fold dies out and another begins at the same time to rise on one side or the other,

there will be, as a consequence, transverse strikes of the strata over the district between the approximate ends of the two folds.

When the character and dip of a rock bed have been fully established, its boundary should be laid down on the map.

It will be inferred from what has been said in Economic Geology of Coal in regard to rocks changing from sandstone to shale, etc., that the bed may also thin out or change its composition or color. Such changes are not signs of new beds.

1403. Identification of Rocks.—The prospector is better equipped for his duties if he has a knowledge of mineralogy, but in the absence of such knowledge rocks may be distinguished to some extent by their physical properties, such as color, etc.

1404. Streak.—Streak is the name given to the powder made when a knife, or file, or diamond is drawn across the surface of a rock, etc. Streak is sometimes useful in distinguishing dark bituminous clays or shales from varieties of coal, the former giving a dull brown or gray powder and the latter a lustrous black.

1405. Color.—Within *certain limits*, some, at least, of the constituents will be indicated by the color. The great coloring matter to which rocks owe their diversities of hue is iron. It gives rise to numerous tints of yellow, brown, red, green, blue, and black.

Frequently we meet limestones and clays which are quite *white*, in which condition they are nearly at their purest. Iron is present only in very small quantities, or is absent altogether. Weathering often results in bleaching the rocks white, the air and rain removing the coloring materials, especially the iron.

Coals, of course, may be distinguished by their lightness, texture, and combustion. Clays or shales rendered black by the vegetable matter they contain may be recognized by their weight, streak, and their turning white, but re-

taining their shape when strongly heated. But black heavy rocks abound *in which there is no trace of carbon.* These generally contain a considerable amount of iron. Such rocks are apt to weather with a brown or yellow crust.

Some rocks are characterized by a *brown* color on fresh fracture, for example, black-band iron-stone. Some mica and garnet and other crystalline rocks have a brown tint due to the presence of mineral of that color. Brown tints appear more particularly on the decomposed surface and crust of rocks.

Gray may be said to be the prevailing color among rocks, especially of the older geological periods. In simple rocks, like limestone, it is often produced by the intermingling of minute particles of clay, sand, or iron oxide, or of carbonate of lime. Pure crystalline limestone is naturally snow white, as in Carrara marble. In compound rocks the prevailing gray hues depend on the mixture of the white mineral, usually a feldspar, with one or more dark minerals, the lightness or the darkness of the hue depending upon the relative proportions of the constituents. Should the feldspar be colored by iron, a pinkish hue may be given to the gray; or, if the dark magnesian silicates have been chemically changed, the gray becomes more or less distinctly green. The old "green stones," probably originally gray, often owe their present distinctive hue to an alteration of their original minerals.

Blue is infrequent in rock masses. Limestones are really gray, or bluish-gray; nevertheless, blue is the color often spoken of as the color of limestone. In schistose rocks a belt of pale blue and white sometimes occurs. Some clays are of a pale lavender hue. Among peat mosses, patches of an indigo tint are frequently met, resulting from the decay of some organism which gave rise to the formation of phosphate of iron.

Green is due to the reduction of iron oxide. Many red sandstones are marked with round spots of green. Carbonates of copper sometimes color rocks a bright verdigris or emerald-green tint. Many magnesian silicates are green

and impart green colors of various hues to rocks of which they are constituents.

Oxide of iron is nearly always the coloring material of *yellow* rocks. Weathered crusts of many limestones, numerous ferruginous crystalline rocks, beds of ocher, and yellow sandstones furnish illustrations. A metallic or brassy yellow is sometimes communicated to parts of rock by diffused iron pyrites.

1406. Smell.—Some rocks, especially limestone, containing animal matter or decomposing iron sulphides, yield a fetid or rotten-egg odor when freshly broken.

1407. Geological Horizon.—As it is impossible to represent the outcrop of every bed on an ordinary map, the prospector must decide what bed should be selected for tracing. Sometimes this outcrop can not be selected until considerable progress has been made. The selection of an outcrop does not depend merely on the geological or industrial importance of the stratum, but also upon the extent to which it is exposed, and can be followed across the district. A peculiar stratum of no special interest in itself may have a high importance as a geological bench or platform, or horizon, if it is easily recognizable, and, from its thickness, hardness, or other peculiarities, stands out so prominently that it can be satisfactorily traced from point to point. Such a stratum may be found in most districts of stratified rocks. Great assistance in the tracing of benches is likewise afforded by organic remains. A particular stratum, even when thin and otherwise of no apparent importance, may acquire a high value if it is charged with fossils and can be recognized over a wide area.

1408. Breadth of Outcrop on Plan.—The outcrop may be marked on the plan at any particular locality by a short line and the dip-arrow, or, if the outcrop is a broad one, by two lines, one marking the base and the other marking the top of the stratum. The space between these two lines (in other words, the breadth of the outcrop) is determined by the thickness of the bed, its angle of inclination, and the slope or contour of the ground.

1409. Continuity of Coal Beds.—When the outcrop is clearly shown, but the coal extends under a more recent formation, there should be no question of the existence of coal under the ground covered by these latter formations, unless some indications of volcanic eruption, or a heavy throw, are found, which may have thrown the strata to a great height. These strata, with the coal they contained, may have been then denuded and planed down, leaving a large area of upturned rocks in which there is no coal. Again, although the coal may be continuous through the whole area, a down-throw fault may have broken the continuity of the strata and thrown the coal measures to an enormous depth. The Whin Dykes, of Scotland, in many cases, throw the coal up or down several hundred feet, and also change the strength of the dip.

Under these circumstances a knowledge of geology may and will help us, but a positive knowledge of the depth of the seam, its dip, etc., can be obtained only by boring. There are exceptions to the continuity of the coal under the overlying measures. In some seams in Western coal fields which outcrop in the beds of rivers nearly 300 feet deep below the level of the prairie, the coal continues under the prairie for miles, broken only by small throws, and then becomes more and more bony, then slaty, and finally changes to pure shale at a depth nearly level with the outcrop.

1410. The Accurate Survey and Map.—The construction of a temporary map has previously been explained, but now, if a more complete map can not be procured, one must be made. A convenient scale is 400 or 500 ft. to the inch, but the size of scale is not of much importance further than that a large plan is unwieldy, while one of small scale requires greater care on the part of the prospector when putting his notes or signs on the map. All the spots where any information can be had regarding the formation must be carefully marked or located on the plan *within the space they occupy.*

The surface survey of any tract of land, shown by the

preliminary survey as likely to contain workable coal, may be made by triangulation. The ground is covered with a network of imaginary triangles, all the angles of which have been measured by placing the transit at each station and noting the angle that the lines make with each other. When the length of the base line and the angle at each end are known, the length of the other lines can be calculated by the rule given in Art. **1387**:

$$\left\{\begin{matrix}\text{Sine of the}\\ \text{angle opposite}\\ \text{the known side}\end{matrix}\right\} : \left\{\begin{matrix}\text{Sine of the}\\ \text{angle opposite}\\ \text{the required side}\end{matrix}\right\} :: \left\{\begin{matrix}\text{Length}\\ \text{of known}\\ \text{side}\end{matrix}\right\} : \left\{\begin{matrix}\text{Length of}\\ \text{required}\\ \text{side.}\end{matrix}\right\}$$

EXAMPLE.—It is supposed the base line *1–2* when measured was 600′, and the transit when set up at *1*, *2*, *3*, and *4* gave the angles as

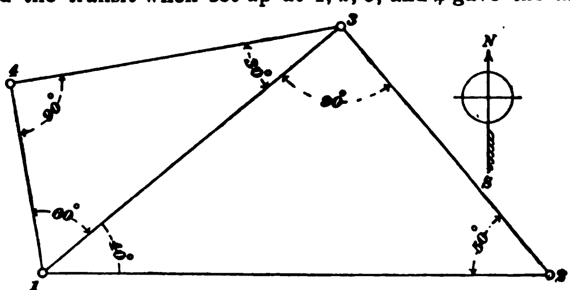


FIG. 397.

they are marked on Fig. 397. What is the length of *1–3*?

SOLUTION.—Applying the above rule:

Sine of 90°. Sine of 50°.
1.0000 : .766044 :: 600′ : 459.63 feet. Ans.

EXAMPLE.—What is the length of *1–4*?

SOLUTION.—

Sine of 90°. Sine of 30°.
1.0000 : .5 :: 459.62′ : 229.81. Ans.

In order to get good results the decimal figures should be carried to at least five places. The first operation, as intimated before, is in selecting the base line. This need not exceed 900 feet in ordinary surveys, if it is carefully and accurately measured. One of the sides of the last triangle should be measured, if the survey is a large one, to check the calculated lengths, and to prove the accuracy of the survey.

The end of the base line should be carefully marked by some prominent object, such as a piece of heavy T rail, or an old car axle, when obtainable, about 3 feet long, driven into the ground, the "point of sight" being carefully marked by a cross (+) mark; or a large-sized stone may be sunk in the ground and a hole drilled in the same at the "point of sight."

Special care must be taken to avoid ill-conditioned angles, that is, triangles should be avoided with angles less than 30° or more than 120° to 150°, because a point is not absolutely defined if the lines fixing it meet at a very obtuse or very acute angle.

The completion of a survey by triangulation is accomplished by the "filling in" of the interior details by surveying, with the transit or compass, the rivers, roads, woods, streams, etc.

1411. Preservation of Notes.—All notes should be carefully preserved either on the plan constructed for the prospector's final examination, or, what is better, in a substantially bound book, so that should the examination of the property develop sufficient facts indicative of successful mining, a working map or colliery plan can be constructed from them.

In order to show the application of what has been said in the preceding articles, two diagrams are given (Figs. 398 and 399).

1412. Prospector's Map.—In Fig. 398 is shown the manner in which data is compiled and recorded on a prospector's map. The shaded parts show what is actually seen by the prospector; over the blank portion he is supposed to have been unable to see any rock in place.

Most all the observations occur along the streams, these being the most frequent natural lines of section. At each point where the dip has been taken an arrow and number mark the direction and angle of dip. The more important or stratigraphically serviceable beds have their outcrops marked in decided lines where actually seen. The outcrop,

where the same stratum can be seen in two adjacent streams, may be drawn across the intervening ground, and the intervening ground should be searched for corroborative indica-

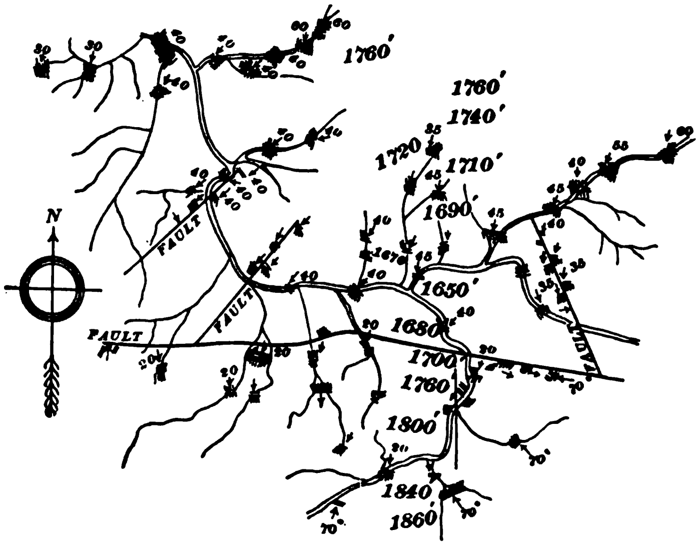


Fig. 398.

tions. The outcrop may be drawn in continuous lines on the plan where there is no doubt regarding its position and direction, but where any doubt exists regarding these points it must be indicated only by dotted lines.

1413. Fig. 399 shows a complete geological plan constructed from the prospector's notes shown on Fig. 398. It will be noticed that the order of succession of the rocks is found to be the same in the different streams. Bed *a*, after an interval, is followed by *b*, *c*, *d*, *e*, *f*, and *g*, but at *h* a fault is met, which throws the stratum *a* to the position shown at *i* (see map and section), which, after an interval, is followed by *j*, *k* (*j*, *k* are the same beds as *b*, *c*), but at *l* something different is met, viz., the same rocks dipping in the opposite direction. The result is plainly shown in section, Fig. 400. Where a blank space occurs, and owing to some surface accumulations a certain bed may not be visible to the pros-

pector in one of the lines of the section, the position of the invisible stratum may reasonably be assumed. In such a case dotted lines are drawn to indicate its probable position.

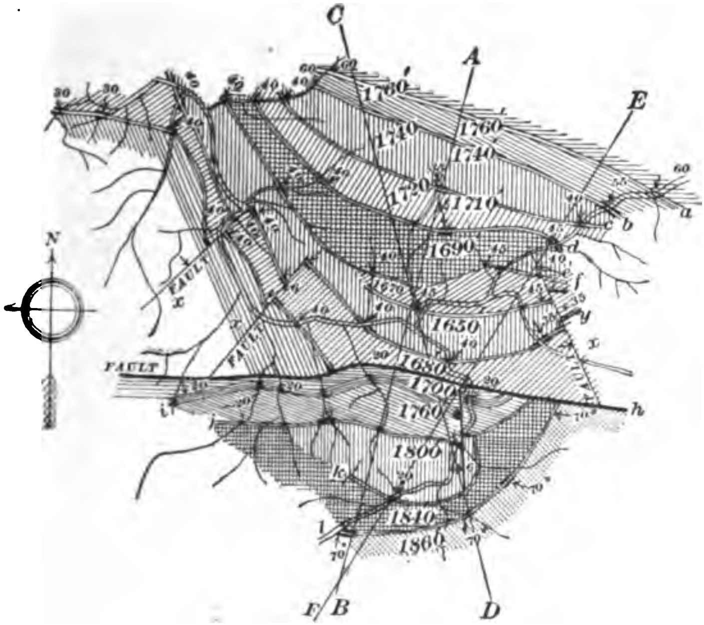


FIG. 399.

A prospector's geological map is therefore constructed from actual data, and from legitimate inference.

1414. In Fig. 401 are shown a few of the conventional characters used by geologists for sections and diagrams when colors are not admissible.

1415. Change of Outcrop.—It will be noticed that although the stratigraphical order is the same in each stream the lines of outcrop differ greatly, diverging and converging as they are influenced by inequalities in the level of the ground, or by variation in thickness of strata, or by variation in angle of dip.

There is still another condition that may influence the stratigraphical order, viz., thinning away of the strata

(Fig. 402). A section is sometimes found where the two lines of outcrop come together, caused by the complete thinning away of the intermediate strata. In this case the

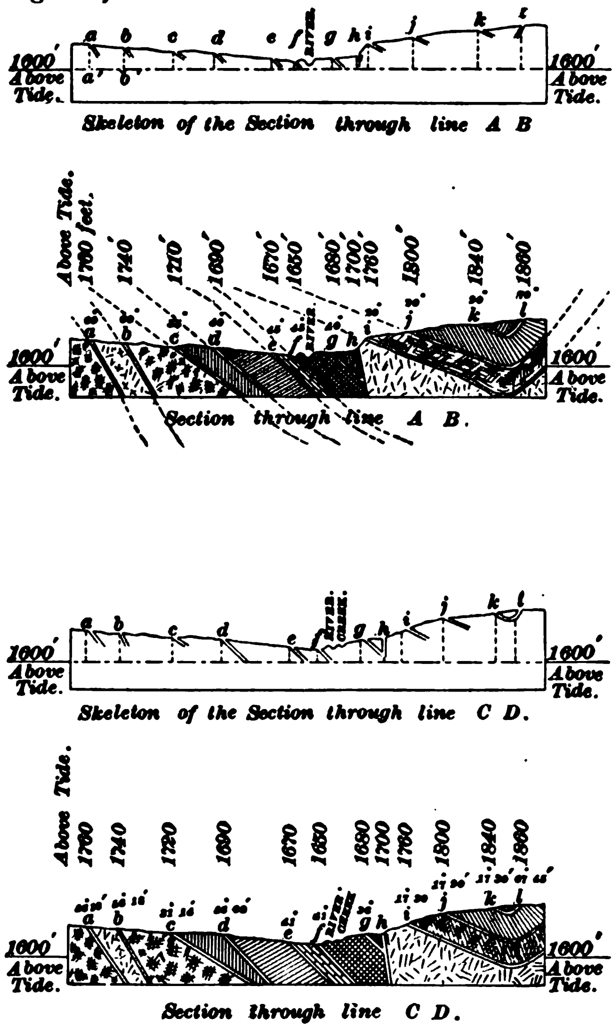


FIG. 400.

conjoining outcrops may be traced for a long distance without any change. The higher portions of a series of strata now and then steal or lap over the lower.

Such a formation can not always be shown on the map, but it is made clear by a section. This structure (see Economic Geology of Coal) may frequently be met with along

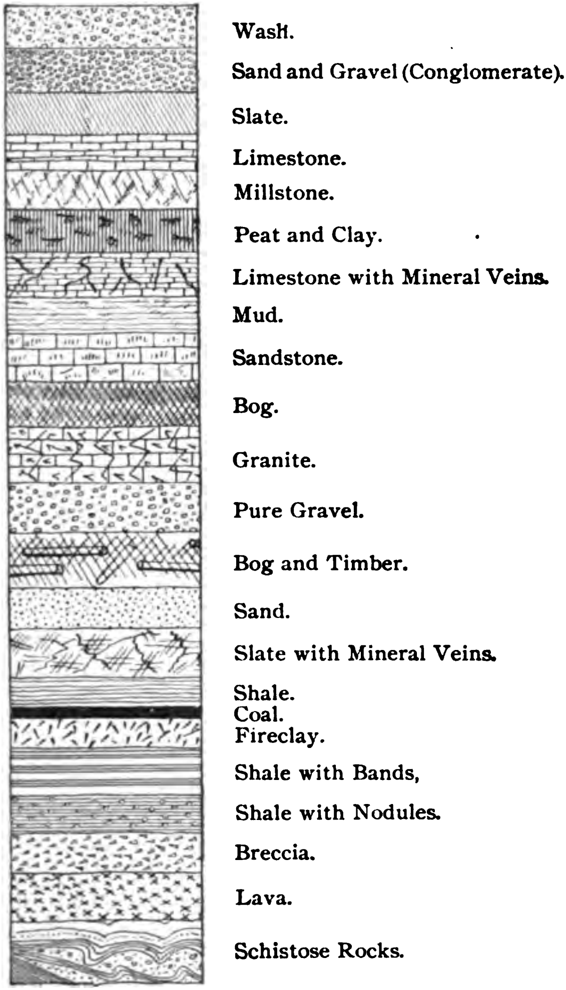


FIG. 401.

the margins of formations deposited in tracts which were undergoing gradual submergence. The strata are parts of one continuous and unbroken series. As the land sank,

successive formations were carried down beneath the sea, and the later deposits of the sea floor were prolonged

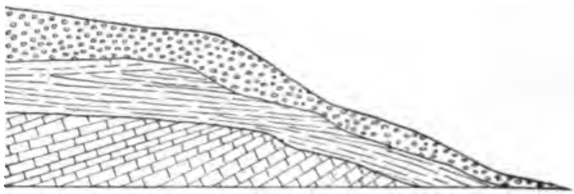


FIG. 402.

further and further beyond the limits of the earlier one. No apparent unconformity can be detected between any portions of them. But where the accumulation of a group has been succeeded by elevation, exposure, and denudation, the next set of strata laid down on this disturbed and denuded group will rest upon it unconformably.

1416. Faults; Dykes.—Intrusive rocks may occur in the form of veins, traversing at any angle the rocks among which they rise, in the form of wall-like masses or dykes, or as irregularly circular masses forming the upper ends of vertical columns or pipes called "necks." Dykes vary from less than an inch in thickness to over 70 feet, and often carry iron which attracts the magnetic needle to such an extent that the dykes can frequently be traced long distances by that means.

Fig. 398 shows several faults, but they are all from the same parent bed. Unless very carefully examined, a minor fault or secondary slip or dislocation may be mistaken for an important and dominant fault, the evidence of which might be elsewhere obtainable, but which might never be seen itself. An exposure of a fracture will give the exact position of the line of fault at that place, but it is not necessary to prove the existence of either the minor or dominant fault, nor will the exposure furnish additional information of any value or importance. As a rule the large faults which powerfully affect and influence geological structures are seldom found in any visible form. In this way three

faults are shown in Fig. 395, yet none of them show any surface indications. Indeed, in many cases, a fault is a line of weakness readily attacked by the forces of denudation, whereby it is hollowed out so as to become a receptacle for superficial deposits which actually hide the fault from view.

1417. Springs Due to Faults.—A spring of water is often due to a fault diverting an underground current of water from its course. The rocks having open joints will conduct the rainfall that reaches the outcrop down to the valley, but a fault crossing the strike throws the rocks up and substitutes a bed impervious to water. The water, being unable to flow downwards to the bottom, finds its way through the covering of clay and soil, and bursts out on the hillside in springs *A*, *A*, Fig. 395. There are many other indications of faults which will present themselves to the prospector, but by far the most important and satisfactory evidence of the existence and effects of faults is furnished by the grouping of the rocks with reference to each other. The nature of this evidence will be most satisfactorily shown in plan in Fig. 399, and in section in Fig. 400. The plan, Fig. 399, and section, Fig. 400, show that the strata found at *a* have been thrown to the surface and are again shown at *i*, which proves that a fault of great proportions (not necessarily wide) exists at *h*.

1418. Dip and Strike Faults.—Faults running with the dip are called "dip-faults" (*x*, *x*, *x*, Fig. 399), while faults running with the strike are called "strike-faults" (*h*, Fig. 399). A dip fault has the effect of shifting the outcrop of an inclined stratum so as to make it appear as if it were horizontally displaced, owing to the way in which denudation has worn down the surface of the ground. In the map (Fig. 399), the beds *f* and *y* are dipping south, and are traversed by dip-faults with a downthrow to the east. The lines of outcrop are consequently shifted northwards on the downthrow side. If the beds had dipped northwards, then a downthrow to the east would have moved the outcrops southwards. A strike fault, when it exactly coincides with

the line of strike on both sides, makes no change in the line of outcrop, except in bringing two different parallel formations closer together. It may, however, carry important strata (coal, for instance) out of sight, or prevent them from being seen at the surface. Thus all the strata under *a* (Fig. 399) can not be seen at the fault, although it crops out north of *a* on the map.

A dislocation may occur in any direction, and cross either dip or strike at any angle; therefore, the dip fault and strike fault are not very sharply marked off from, but may pass into, each other. A fault is generally designated by the direction it throws from the place first met in mining. Thus, if the strata have dropped at the place the fault is first met it is a downthrow, if the strata have been thrown up it is an upthrow.

1419. Thrust Fault.—Dislocations sometimes assume the form of inclined or undulating planes, the rocks above having been pushed over those below by lateral pressure. In such cases, the horizontal displacement is very great. This is sometimes termed an overthrust.

1420. Advantages of Sections.—Some clearly constructed maps do not need any section, except to show data which can not be expressed on the map, as some cases of overlap. But such clear maps can seldom be constructed. Clearly constructed sections save both time and labor, as they enable the structure of the district to be seen and comprehended almost at a glance.

1421. Horizontal and Vertical Sections.—Two kinds of sections are made, horizontal and vertical. They may show what would be seen if a deep trench were cut across the hill and valley so as to expose the relation of the rocks to each other; or they may exhibit the arrangement and thickness of the rocks as they would appear if piled into a tall column one above the other in their proper order of succession. This latter section is chiefly useful in detail work among coal fields where the various strata of one pit, or a part of a district, may be compared with those of

another. This class of section requires good exposures and careful measurement.

The construction of the horizontal section is different. It may be necessary to construct a section of a district where exposures are few, where minute measurements are impossible, and where the best skill of the prospector is required to unravel the meaning of the facts noted upon the surface, and show their bearing on the rocks below ground. A section of this kind should be constructed so that the heights and lengths are on the same scale, if possible. When the ground is comparatively level, to use a scale large enough to show the elevations and depressions would make the section exceedingly long on paper. In such a case it would be best to use a larger scale for the vertical heights than for the horizontal distances, but exaggerating the height of the section should be avoided as much as possible.

Sections are generally drawn at right angles to the strike, but in special cases, to make clear certain formations, they may be drawn at any angle from the strike.

1422. Section and Curvature of Strata.—Having obtained the elevations of the points on the surface through which the section runs, the next step is to lay off on a base line, or datum, measurements to scale, showing the horizontal distances between the points. From these points on the datum perpendicular lines must be drawn, and the height of each point marked by scale on its perpendicular, as in skeleton section of Fig. 400. A line is then drawn connecting all the points. This gives the general contour of the ground. More details can be secured by taking the skeleton section in hand and walking over the ground, filling in all little inequalities of surface. This may also result in securing more evidence as to the nature and structure of the rocks. Some of the data for such a section may be secured in places at some little distance from the actual line of the section. The skeleton section (Fig. 400) shows what is exposed to the view, while the complete section is constructed from these exposures and the logical inferences that

TABLE 29.

OBLIQUE SECTIONS.

$b =$		5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°
		Corrected Angles.											
$c =$ 5°	...	4° 59′	9° 58′	14° 57′	19° 56′	24° 55′	29° 50′	34° 54′	39° 51′	44° 53′	49° 54′	54° 54′	59° 54′
$c =$ 10°	...	4° 55′	9° 51′	14° 47′	19° 43′	24° 40′	29° 37′	34° 35′	39° 34′	44° 34′	49° 34′	54° 35′	59° 37′
$c =$ 15°	...	4° 50′	9° 40′	14° 31′	19° 22′	24° 15′	29° 09′	34° 04′	39° 02′	44° 00′	49° 01′	54° 04′	59° 08′
$c =$ 20°	...	4° 42′	9° 25′	14° 08′	18° 53′	23° 40′	28° 29′	33° 21′	38° 15′	43° 13′	48° 14′	53° 18′	58° 26′
$c =$ 25°	...	4° 32′	9° 05′	13° 39′	18° 15′	22° 54′	27° 37′	32° 24′	37° 15′	42° 11′	47° 12′	52° 19′	57° 04′
$c =$ 30°	$a =$	4° 20′	8° 41′	13° 04′	17° 30′	22° 00′	26° 34′	31° 14′	36° 00′	40° 54′	45° 54′	51° 03′	56° 18′
$c =$ 35°	...	4° 06′	8° 13′	12° 23′	16° 36′	20° 54′	25° 19′	29° 50′	34° 30′	39° 19′	44° 56′	50° 20′	54° 49′
$c =$ 40°	...	3° 50′	7° 42′	11° 36′	15° 35′	19° 39′	23° 51′	28° 16′	32° 44′	37° 27′	42° 25′	47° 34′	53° 00′
$c =$ 45°	...	3° 32′	7° 06′	10° 44′	14° 26′	18° 15′	22° 12′	26° 21′	30° 41′	35° 16′	40° 07′	45° 17′	50° 46′
$c =$ 50°	...	3° 13′	6° 28′	9° 47′	13° 10′	17° 28′	20° 22′	24° 14′	28° 20′	32° 44′	37° 27′	42° 33′	48° 05′
$c =$ 55°	...	2° 52′	5° 46′	8° 44′	11° 47′	14° 58′	18° 19′	21° 53′	25° 42′	29° 50′	34° 21′	39° 19′	44° 59′
$c =$ 60°	...	2° 30′	5° 02′	7° 38′	10° 19′	13° 07′	16° 06′	19° 17′	22° 45′	26° 34′	30° 27′	35° 32′	40° 54′

may be made. Along the limited exposures of strata usually visible, the planes of dip often seem to be straight lines. Bed succeeds bed, inclined, and forming a succession of parallel bands. But if the section could be continued downwards beneath the surface, or the rocks exposed on the bare steep side of a great mountain, it would be observed that though, when examined within the limited area of a few yards, the beds look as if they sloped in straight, stiff lines, in reality they are portions of great curves, as shown by dotted lines in Fig. 400.

An exact method, however, of determining the underground curves from surface dips can not be devised, and in the absence of exploratory bore holes, the depth and curvature of a coal or other mineral bed can be indicated only approximately, and by very imperfect methods.

1423. Oblique Section.—In order to draw an oblique section, such as a section through line *C D* in Fig. 399, the necessary correction of the true dip must be made by means of the following formula:

a = tangent of angle of corrected dip;

b = angle of dip at right angles to strike;

c = angle at which the section lies to right, or left, of the full dip.

$$a = \tan b \times \cos c. \qquad (84.)$$

EXAMPLE.—Angle of dip is 45°, and the oblique section line runs at an angle of 30° from the true dip; what will be the dip on line of oblique section?

SOLUTION.—Tan of 45°, or 1.0000, × cos of 30°, or 0.866 = 0.866 = tangent of 40° 54′. Ans.

The accompanying table of Oblique Sections, calculated from the above formula, gives the correction for the most useful angles.

1424. Boring and Trial Shafts.—By referring to Fig. 403 (which is a section showing anticlinal and extension of coal field, entirely concealed by new formations, only discoverable by boring), it will be seen that surface exposures, although of great value to the prospector because

they lead up to logical conclusions, are not all-sufficient Under such circumstances as indicated on the right of Fig.

FIG. 403.

403, and many other conditions, recourse must be had to trial shafts and boring in order to get the necessary data to complete the map, so that it will be in shape to indicate conclusively at which point the openings may be most advantageously and economically located.

A shaft will show the ground more plainly than a bore hole, but the cost of sinking beyond shallow depths bars it out. A prospect shaft seldom exceeds 200 feet, and cases where it reaches this depth are exceedingly rare. Apart from the consideration of cost, the consideration of time is all important. Prospecting by drilling is more rapid. When the property, however, has been drilled and otherwise thoroughly investigated, a trial shaft should, when practical, be sunk to prove the quality of the coal, the nature of the roof and bottom, etc. Boring, while proving the *existence* of coal, can not give an adequate knowledge of its commercial value. This can be secured only by driving into the seam sufficiently far from the surface to get a good average sample of the coal.

Some seams are so largely made up of bony çoal and other inferiorities that in appearance are like good coal that boring does not always afford reliable data, and when the shaft is sunk to develop the coal it turns out unsalable.

The experience of the past few years in coking Appa-

lachian coals affords assurance that their coking properties can be estimated with a good degree of confidence by the ratio of volatile hydro-carbons to the fixed carbon. Nevertheless, it is only by practical tests that any coal can be properly judged as to its coking properties, and the value of the coke for metallurgical and other uses.

Thick seams, reported as having been proved by boring, sometimes turn out on investigation to be largely made up of more or less thick layers of worthless materials interstratified with good coal.

A drill furnishing a core is less liable to deceive in this respect than those which furnish only ground samples fished out by a sludger, cleanser, or sand pump.

Coal seams are sometimes practically valueless, owing to the roof being so rotten or dangerous, and so expensive to maintain or carry, that the coal can not be profitable mined.

In some cases it may happen that the overlying strata contain so much water, or are so loose and sandy, that mining operations beneath are quite impracticable. A better idea of these conditions is obtained by sinking a trial shaft or drift and driving a heading or two into the seam.

The strata of some districts contain so much water that it is necessary to have the first shaft sunk large enough to facilitate putting in large pumping fixtures. In such a case the prospect shaft should be carefully located and of such size that, should the coal be workable, it may be used as one of the principal openings in the future development.

1425. The two chief methods of boring are:

1. By percussion drill, which chips the rock into small fragments, subsequently removed.

2. By a rapidly revolving ring, which grinds the rock in an annular space into dust.

The machines classed under the above headings will be described later.

1426. Systematic Record of Details.—The systematic recording of all details in a prospect is the most important part of the whole proceedings. Cases are on record where a district was prospected by boring, twice

within ten years, because the people in charge the first time did not keep a written record of any bore holes, unless to simply note the existence of the particular mineral of which they were in search.

A very accurate system must be adopted for recording strata passed through by bore holes. The accompanying specimen page of a journal shows the system used by a borer of long experience.

Journal of boring executed at..................................., *County of*...................................
State of..................................., *on property of*...................................
Began..................................., *189* ; *Completed*..................................., *189*
Names of men at work...................................
....
Name, number, or letter of bore hole as indicated on map...................................

Date.	Description of Strata.	No. of Specimen in Case.	Thickness. Ft. In.	Depth from Surface. Ft. In. to Ft. In.	Direction of Dip and Angle of Inclination.	Diameter of Bore Hole.	Description of Tool Employed.	Time Actually Occupied in Passing Through	Quantity of Water Met With.	Organic Remains, Fossils, etc.	Remarks.

1427. Classification of Boring.—Boring may be classed under two heads:

1. Boring to prove the continuity of the seams or beds indicated by surface exposures, etc.

2. Boring where there are absolutely no surface indications—boring in the dark.

1428. How to Find the Dip.—To explain the first system of boring let us suppose a tract of land such as is shown in Fig. 404. At *A* the strata, dipping at an angle of 21° 30′, crops out, or is reached by a shallow trial shaft. This dip must be verified.

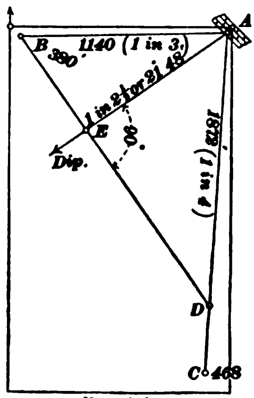


FIG. 404.

The bottom of hole *B* is 380 feet deeper than *A*; therefore, 1,140 feet (the length) ÷ 380 feet (depth) = 3, or 1 in 3 is the inclination of the line *A B*.

The bottom of the hole *C* is 468 feet deeper than *A*; therefore, 1,872 feet (the length) ÷ 468 feet (the depth) = 4, or 1 in 4, is the inclination of line *A C*.

If points are located at a distance of 3 feet from *A* on line *A B*, and of 4 feet from *A* on line *A C*, and connected, the connecting line is at right angles to the true dip, but the distances 3 and 4 feet are too short for exactness. Divide 1,140 (length of line *A B*) by 3, and multiply the quotient by 4 (the dip of line *A C*), thus:

$\frac{1,140}{3} \times 4 = 1,520$ feet, or the distance along line *A C* which will mark a point on the same level as the bottom of the hole at *B*. Connect this point, which is designated *D*, with *B*, and the line will be the "strike" at right angles to the true dip, and of course a line drawn at right angles to this line *D B* will itself be the line of true dip. By measuring with a scale the length *A E* and dividing it by 380 feet—for every point on the line *B D* is 380 feet below the level of *A*—the true inclination is found.

Thus, if line *E A* scales 950 feet, then $\frac{950'}{380'} = 2.5$, or 1 in

2.5 = cotangent of 21° 48′, which practically agrees with the clinometer reading at *A*.

If the result did not agree with the pitch shown by the clinometer on the rocks at *A*, then there must be a fault between or the dip has changed in strength.

How far must the line *A B* be extended beyond *B* so that a drill hole will strike the stratum *A* at the same depth it is in the bore hole at *C*, the surface being level?

468 feet (depth of hole *C*) — 380 feet (depth of hole *B*) = 88 feet. As there are 3 feet in length for every foot in depth along line *A B*, all that is necessary is to multiply 88 feet by 3 feet, resulting in 264 feet as the length *A B* will have to be extended to reach the same depth as bottom of the hole at *C*.

In the same manner the true dip may be found by three bore holes, where there are no exposures whatever. It is only right to say that these calculations are often upset by faults running between the positions of the bore holes.

1429. Another case is shown in Fig. 405. In the north river seams crop out at *A*, *B*, and *C*.

The thickness of each seam and the nature of the strata over and underlying each must be carefully noted. By the

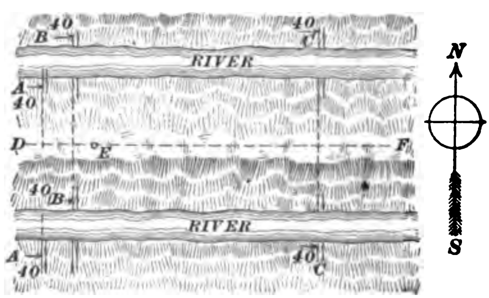


FIG. 405.

aid of the clinometer the dip of the measures is obtained, and by the pocket compass the "strike" or level lines of the seams are found to run in the direction of the dotted lines from the north to the south river. Following these lines to the south river, the same seams are found cropping out at

A, *B*, and *C*. By drawing the lines from *A* on the north river to *A* on the south, the probable outcrop of that seam is shown. The same will be true of the other two seams.

This outcrop may be verified by the following method: From the point *D* on the outcrop line *A A*, draw a line *D F* on the map at right angles to the line *A A*. Supposing the surface to be level from *D* to *F*, measure off a distance, say 100 yards, from *D* to *E*. As the angle of dip of the seam *A A* was indicated by the clinometer, the depth at which the seam *A A* lies below *E* can be calculated by a similar method. The distance from the probable line of outcrop of *B B* to *E* may be calculated, and also the angle of dip of *B B* being known, the depth at which *B B* underlies *E* may be calculated.

Supposing the angle of dip of each seam is 40°. If the distance from *D* to *E* is 100 yards, or 300 feet, then having the horizontal distance *D E*, as measured on the level surface of the ground, and the angle 40°, by multiplying the distance *D E* by the natural tangent of the angle, the required depth is found.

In this case the distance is 300 feet. The natural tangent of 40° is .8391; therefore, $.8391 \times 300' = 251.73$ feet deep, from the surface at *E* to seam *A A* vertically below point *E*.

In the same manner, if the distance from the probable line of outcrop of coal *B B* is 150 feet to *E*, then $.8391 \times 150$ feet $= 125.86$ feet deep from surface at *E* to seam *B B* vertically below point *E*.

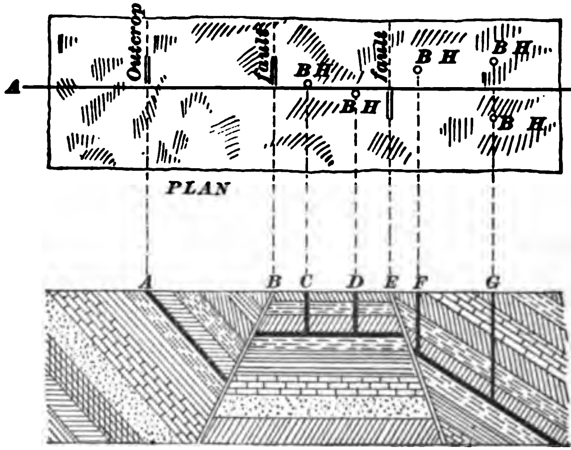
The same results can be obtained by the rule given in Art. **1387,** if it is remembered that one angle of a right-angled triangle is always 90°, and the third angle can be found by subtracting the given angle + 90° from 180°.

By putting down another hole at *F* and calculating the depths in the same way, it will be known at what depth to expect all the seams *A A*, *B B*, and *C C* at *F*.

Care must be taken in setting out the line *D E F* at right angles to the line of outcrop, or otherwise the true angle of dip will not be obtained.

1430. Fig. 406 shows in plan and section a complicated piece of ground which can be proved only by boring. In this case the seam was opened by a slope at *A*, which ran against the fault *B*, which was then carefully looked for and located on the surface.

Bore holes *C* and *D* were put down and located the seam



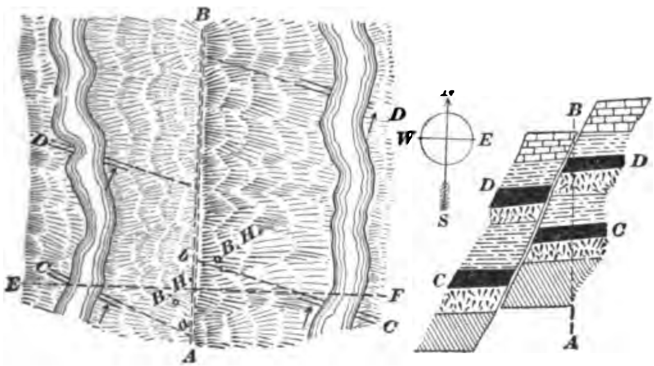
Section through line *A B* on plan.

FIG. 406.

at equal depth. Then the hole *F* was put down, and it found the seam at a greater depth than the two former holes, making additional data necessary. Therefore the two holes *G* were put down, and they, with the hole *F*, furnished the data by which the angle and line of dip was proved. They also made evident the existence of the fault *E*.

1431. Fig. 407 shows conditions where some difficulty will be experienced in proving the "lay" of the various seams. If the probable line of the outcrop of *C* is followed, as indicated by the dotted line *C a* from the west river, no crop will be found in the east river. But on going up the east river, an outcrop corresponding to *C* on the west river will be found. A survey of it indicates the crop traveling in the direction of the dotted line *C b*. By traveling up the streams the same conditions are again met. Why do these

indicated crop lines not lead to the seam on the other river, is a natural question. There must either be a swelling of the strata between the outcrops or there is a fault of vari-



Plan.

Section at right angles to line *A B* through the line *E F*.

FIG. 407.

able throw between the two rivers. To prove which of the two assumptions is correct, a number of trial shafts or shallow bore holes must be put down, as the rules previously given can not be successfully applied.

1432. Trial Shafts.—Good laborers will sometimes sink a shaft ten feet deep without a staging, that is, a platform to throw the dirt on.

When the depth exceeds ten feet, it is necessary to build a staging or cut a step to throw the earth upon (from which it is again shoveled and thrown from the pit), or to erect a windlass for hoisting.

When the depth exceeds fifteen or eighteen feet a windlass becomes necessary. This may be a very primitive affair, but should be strongly built. A hemp rope one inch in diameter and a strong iron-bound wooden bucket holding about 80 or 100 pounds complete the outfit.

The upright upon which the rope shaft rests should be securely braced both at the sides and back.

Some men prefer sinking square shafts, others prefer sinking round holes. If the ground is firm, the shape is a matter of minor consideration. A rectangular hole about

4 feet × 5 feet gives sufficient working room, and is for some reasons preferable to any other form.

A square shaft is best adapted to sinking in loose treacherous ground, which threatens to cave in and needs heavy timbering. Theoretically a hexagonal or octagonal hole is better under these conditions, but it is difficult to cut the joints and fit the timbering with sufficient accuracy to yield the requisite resistance to side thrust, whereas square timbering is easily fitted, and not so apt to become displaced, and is, moreover, much cheaper.

The timbering is kept in place either by supporting beneath or hanging it from above, being of course in either case wedged in place as tightly as possible by wedges and by a series of boards, waste slabs, or small round pieces driven in behind the timbers.

Round timbers, six or eight inches thick, may be used for the crib work, but square timbers are better, as they can be more easily and accurately fitted.

The distance between the cribbing girths, that is, the distance between each set of framed timbers, will depend entirely upon the character of the ground and depth to which timbering is necessary. It is never advisable to place them more than six feet apart, and generally they should be closer together.

One end, side, corner, or the center of the pit is kept in advance of the average level of the shaft bottom, thus providing a sump for the water, as well as giving a loose end to the material being excavated.

1433. Conditions Requiring Special Attention.—By referring to Fig. 403 it will be seen that the two bore holes shown at *E* and *F* reach the seams *C* and *D* at the same level, and through lack of any surface indications, it would naturally be supposed that they are the same seam, unless there is a marked difference in the composition of the coal, or in the overlying or underlying strata. To detect these differences requires a close scrutiny of the borings.

In boring there are many geological peculiarities which

sometimes tend to deceive the prospector. For instance, suppose two bore holes are put down at *A* and *B* (Fig. 408), say 3,000 feet apart. The bore hole at *A* proves a seam 3

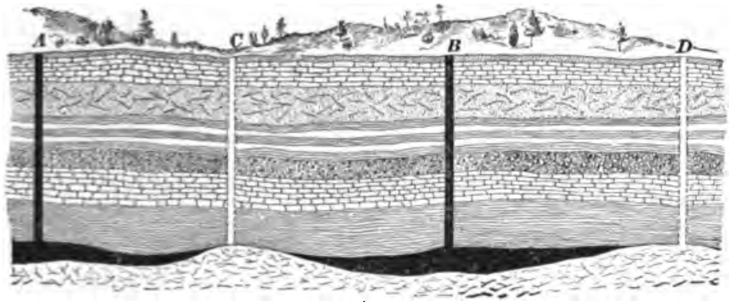


FIG. 408.

feet thick, and at *B* the coal is found at about the same level 6 feet thick. It would be natural to suppose that this seam was one which was gradually thickening as it went from *A* towards *B*, and that it would be found about four feet thick at *C*, or seven to eight feet thick at *D*; whereas, it is only a streak, or there is no trace at all at these points. These pockets of coal are frequent, and very deceptive to the inexperienced.

Again, if bore holes were put down at *C* and *D*, finding no coal but Sub-Carboniferous strata instead, that does not absolutely prove there is no coal, for a hole at *A* or *B* would find coal. These are samples of conditions that are frequently met in some of the American coal fields.

1434. The splitting of coal beds is a very common occurrence, and this should always be watched for in boring. It is not sufficient simply to bore down to the bottom of a seam whose existence is to be proved. For instance, in Fig. 409 bore holes have been put down at *A* and *B*. Each of these proves a seam of coal at about the same depth and of the same thickness. If the bore hole *B* had been deepened it would have shown quite different results.

As some coal beds are so much cut up and disturbed by "clay veins," "horses," etc., as to become unworkable at a profit, it is necessary for the prospector to scan the

outcrops for them, and in boring to anticipate them and make all due allowances.

It should be remembered that sandstones are apt to vary

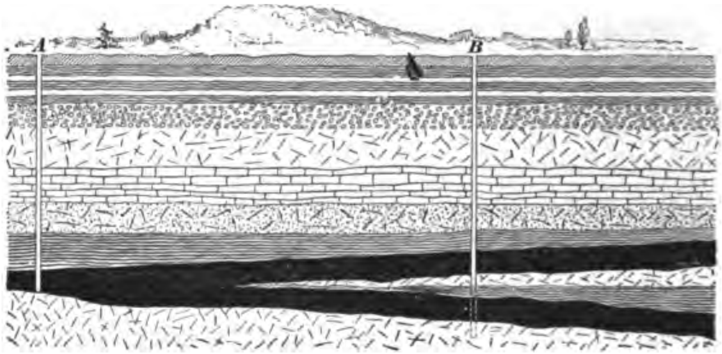


FIG. 409.

in thickness and persistency more than the other varieties of rock in the coal measures; therefore, they do not afford such reliable evidence of the near existence of coal seams as strata of other kinds of rock.

Wherever organic matter is found, whether in the form of fossils or coal, the sandstones and shales are white or gray. All sandstones of the Carboniferous measures, or of other strata, containing coal are gray, while the old red sandstone below the coal and the new red sandstones above the coal, and, in fact, all red sandstones, are very poor in fossils or evidence of organic matter of any kind.

1435. Before leaving this subject, one more instance, embracing both conditions, will be given.

The imaginary line about which the beds may be supposed to be bent is called the axis of the anticline or the syncline. This axis may be either horizontal or inclined. If it is horizontal, sections taken in any part will show the same beds. But if it is inclined, different sections will cut different beds. Prof. Jukes, of the British Geological Survey, gives the example shown in Figs. 410, 411, and 412. Fig. 410 is a plan of undulating beds, the axis of the anticlinal and synclinal curves being inclined—in this case

dipping to the north, as shown by the arrows. It is plain

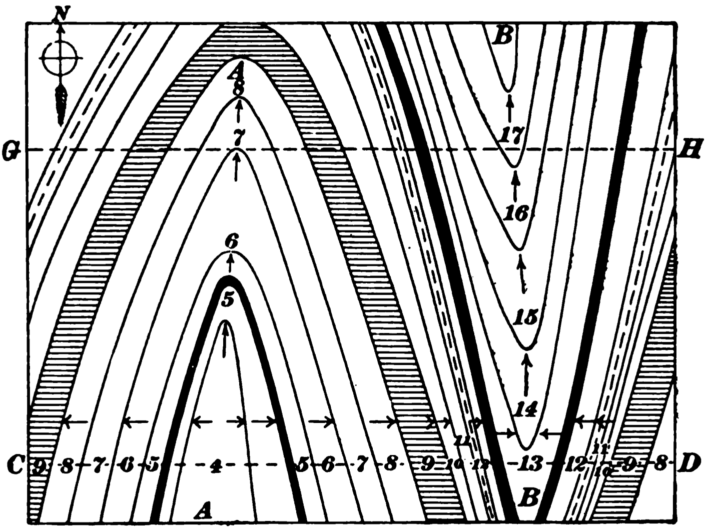


FIG. 410. Plan.

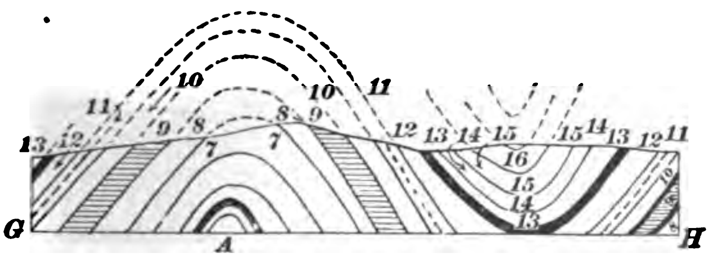


FIG. 411. Section through *G H*.

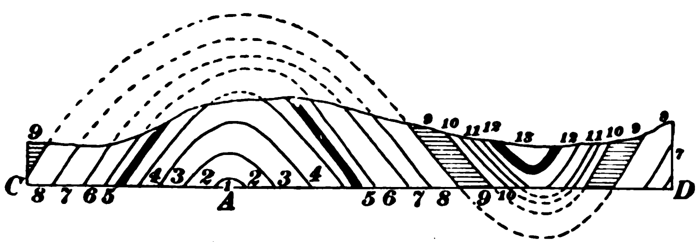


FIG. 412. Section through *C D*.

that unless the surface of the ground slopes with the axis, other beds must come in, arching over each other in the

case of the anticline, or resting upon each other in the case of a syncline. Thus, bed No. *4* will "nose in" under the new bed No. *5*, which, in its turn, will "nose in" under No. *6*, and so on. In like manner, in the syncline, bed No. *14* will "nose out" over No. *13*, No. *15* over No. *14*, and so on. Hence, if a section is taken along the line *C D* in the plan (Fig. 410), such a section will appear as in Fig. 412, in which bed No. *4* forms the crest of the anticline, and bed No. *13* is the highest in the syncline. But if a section be taken along the line *G H*, this section will appear as in Fig. 411, in which bed No. *7* forms the crest of the anticline, and bed No. *16* is the highest in the syncline. It is of the utmost importance to observe carefully the inclination of the anticlinal and synclinal axes.

1436. Sir Charles Lyell has probably presented this matter clearer than ever before:

"There are endless variations in the figures described by the basset-edges (outcrops), according to the different inclinations of the beds, and the mode in which they happen to have been denuded.

"One of the simplest rules with which every prospector should be familiar relates to the **V**-like form of the beds as they crop out in an ordinary valley. First, if the strata be horizontal the **V**-like form will be also on a level, and the newest strata will appear at the greatest height.

"Second, if the beds be inclined and intersected by a valley sloping in the same direction, and the dip of the bed be less steep than the slope of the valley, then the **V**'s, as they are often termed by miners, will point upwards (see Fig. 413), those formed by the newer beds appearing in a superior position and extending highest up the valley, as *A* is seen above *B*.

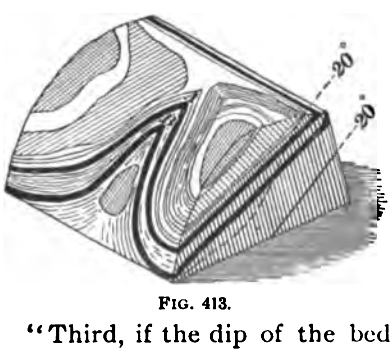


FIG. 413.

"Third, if the dip of the beds be steeper than the slope

of the valley, then the **V's** will point downward (see Fig. 414), and those formed of the older beds will now appear uppermost, as *B* appears above *A*.

"Fourth, in every case where the strata dip in a contrary direction to the slope of the valley, whatever be the angle of inclination, the newest beds will appear the highest, as in the first and second cases. This is shown by Fig. 415, which exhibits strata rising at an angle of 20° and crossed by a valley which declines in an opposite direction at 20°.

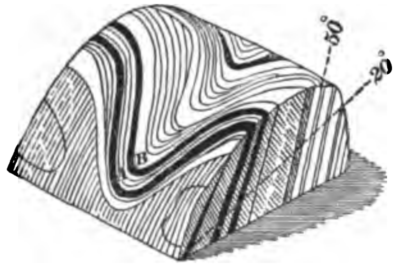


FIG. 414.

"A prospector unacquainted with the rule, who at first explored the valley (Fig. 413), may have sunk a vertical shaft below the coal seam *A*, until he reached the inferior bed *B*. He might then pass to the valley (Fig. 414), and discovering there also the outcrop of two coal seams, might begin his workings in the uppermost in the expectation of coming down to the other bed *A*, which would be observed cropping out lower down the valley. But a glance at the section will demonstrate the futility of such a hope."

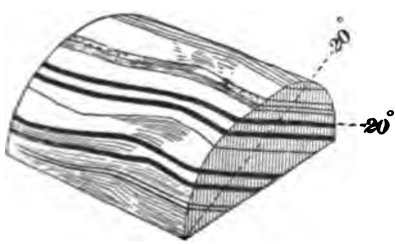


FIG. 415.

DETERMINATION OF QUALITY AND QUANTITY OF COAL.

1437. Sampling.—The prospector in selecting a sample for analysis must bear in mind that his prime object should be to secure a sample fairly representing the average quality of the coal to be shipped to the market. He must not select a sample that will represent the coal in the bed, for that condition may be improved upon in

preparing the coal for market. Neither is it advisable to select a fine specimen, or sample, for that will represent a better coal than can be prepared for the market, unless the coal is perfectly free from impurities and has the same constituents throughout its whole composition, which is not to be expected.

Sometimes a bituminous coking coal at the surface is found to graduate into a cannel coal or a block coal when the field has been penetrated some distance; therefore, great attention should be paid to the change presented in the coal as the prospect advances, and the sample taking should be postponed until the true coal of the bed is reached.

If the sample is to be taken from a drift, tunnel, or slope driven in far enough to show the true quality of the coal, a small piece should be taken from every inch of the seam, care being taken that the fragments shall be of equal amount from each part of the bed, so that they will make such a sample as would be obtained by cutting out a block of coal 3 inches to 4 inches square (or more) and as high as the bed is thick.

The parting bands of slate, sulphur (pyrites), etc., should always be included in the sample, unless the bed contains a thick layer of slate or bone that readily breaks loose from the coal and can be cleaned from the coal in mining. In this case the parting may be represented in the sample by such a piece as would be taken if the parting were only a thin layer.

Sometimes different beds of coal of entirely different quality come together or are separated only by a very thin layer or parting, and are suitable for different uses, such as steam making, domestic use, gas making, etc. In such a case a fair sample should be taken of each quality to show the percentage of each constituent, and a sample of the full thickness of all the qualities to show the general percentage of their constituents.

The same attention should be given in each case to bone, sulphur, etc., as mentioned before.

After the sample has been fairly selected, it should be carefully broken into smaller pieces on a clean floor or iron plate, and then thrown up in a conical pile and quartered. Two quarters opposite each other should be thrown out. The remaining quarters should be broken, made still finer, mixed, heaped up in a conical pile and quartered as before, and this process should be repeated, in large samples, until only a small keg full is left from which the analysis should be made.

When the analyses are made the contents of this keg should be again quartered, ground finer, and requartered, until only enough is left to fill a few small vials, each vial containing sufficient for one or two analyses.

When the sample obtained is a small one it should be ground and quartered, each quarter being ground again and requartered until a powder as fine as flour is secured.

Fill four vials with the pulverized coal of the last quarters, that is, one vial from each quarter, resulting from each of the first four quarters. The mean of the analyses of these four parts of the original sample will be a true representation of the constituents of the coal in percentage; or, these four parts may be carefully mixed and quartered until just sufficient for the analysis remains, and such an analysis will also be a true representation of the constituents of the coal in percentage.

1438. Analyses.—A proximate analysis of coal determines readily, without any costly appliances or much skill, the proportion of water and ash present in any given specimen of coal, and the proportion which volatile matter bears to the carbon, and this is all that is required to determine the value of coal as a commercial commodity. The mode of conducting such an analysis is as follows:

Moisture.—Dry 2 grammes of the coal, finely pulverized, in a weighed platinum crucible (a tarred watch glass or a flat-bottomed iron pan may be used) at 220° to 240° Fahr. for half an hour, cool, and weigh. Dry again for 15 minutes at 220° to 240° Fahr., cool, and weigh again. Repeat this

until the weight begins to increase, indicating incipient oxidation. From the lowest weight thus obtained calculate the percentage of moisture. (The notes further on will show the calculation.)

Volatile Combustible Matter—Hydro-Carbons.—Heat the above crucible and contents for three minutes (keeping the crucible closely covered) in the strongest heat of a good Bunsen burner, or other hot flame, then immediately heat for the same length of time over the blast lamp, cool, and weigh. The crucible should be kept covered throughout the operation. The loss is volatile combustible matter with half the sulphur, because sulphur existing as pyrites may be regarded as volatile or combustible. For anthracite, or coals containing no bituminous matter, this operation is unnecessary.

Fixed Carbon.—Remove the cover and burn off the remaining carbon over a Bunsen burner, or other hot flame, until nothing remains but the ash. The loss is fixed carbon with the remainder of the sulphur.

Ash.—The final weight, less the weight of the crucible, gives the ash.

1439. *Sulphur.*—The determination of the quantity of sulphur contained by a specimen of coal presents greater difficulties than that of the moisture, hydro-carbons, or ash, and for correct results requires appliances and processes belonging more particularly to the laboratory. However, it is frequently necessary to *estimate* the quantity of sulphur, and the following method is given:

Fuse one gramme of the finely pulverized coal with a mixture of ten grammes of carbonate of soda, and six or seven grammes of nitrate of potash. Heat gently at first and until fusion is calm, then continue heating for about a quarter of an hour. Dissolve the contents of the crucible in water, add slowly just enough hydrochloric acid until the solution turns blue litmus paper red, and evaporate to dryness to render silica insoluble. Redissolve in dilute hydrochloric acid, filter off the silica, and precipitate the sulphur

in the filtrate by means of choride of barium. Allow the precipitated sulphate of barium to stand undisturbed for several hours. Then filter, wash well on the filter, ignite, and weigh. Multiply the weight in grammes of the sulphate of barium by 0.13734, and the result will give the weight in grammes of the sulphur.

1440. Notes.—The following is perhaps the most convenient method of keeping the notes of a coal analysis:

Weight of crucible and coal	32.0000 gms.	
Weight of crucible	30.0000 gms.	
Coal taken	2.0000 gms.	
Weight of crucible + coal	32.0000	
Weight of crucible + coal, after drying	31.9920	
Loss = water	0.0080	= 00.40%
Weight of crucible + coal, dried	31.9920	
Weight of crucible + coal, heated (closed)	31.4480	
Loss = volatile combustible + ½ S.	0.5440	= 27.20%
Weight of crucible + coal, heated (closed)	31.4480	
Weight of crucible + coal, heated (open)	30.1000	
Loss = fixed carbon + ½ S	1.3480	= 67.40%
Weight of crucible + contents, heated (open)	30.1000	
Weight of crucible	30.0000	
Residue = ash	0.1000	= 5.00%
Sulphur		1.00%

REPORT.

Moisture	0.40%
Volatile combustible (27.20 less 0.5 or ½ S)	26.70%
Fixed carbon (67.40 less 0.5 or ½ S)	66.90%
Ash	5.00%
Sulphur	1.00%
	100.00%

NOTE.—The several percentages are found by dividing each remainder by the weight of the original sample, which in this case was 2 grammes.

For accurate analysis a good balance, of course, is

essential, but for the prospector's purpose a less costly and less delicate balance will suffice.

The prospector should be familiar with the varieties and characteristics of the different coals as given in Economic Geology of Coal, and also with the following :

In anthracite volatile matter is usually less than 7%.

In semi-anthracite volatile matter is usually less than 10%.

In semi-bituminous volatile matter is usually less than 18%.

In bituminous volatile matter is usually more than 18%.

A few analyses of anthracite and bituminous coals, lignites, and peats (the moisture excluded) are given with the Tables and Formulas for comparison with the prospector's results.

1441. Calorific Power of Coal.—The same difficulty is met in determining the calorific power of coal as in judging of the coking properties. The calorific power, which is the total heat developed by coal on combustion, has a much greater importance than is understood by consumers. One coal may be bought cheaper than another, but if the low-priced coal has less calorific power than the other coal, the purchaser may not be getting the best value for his money. Coals rich in oxygen never have such high calorific power as those containing a smaller amount. The larger the proportion of volatile matter present, the lower is the calorific power of the coal. That the calorific power varies as the proportion of fixed carbon after distillation has been shown by many eminent chemists.

Mix 1 gramme of the finely powdered coal carefully with not less than 20 or more than 40 times its weight of finely sifted litharge containing no metallic particles. Place the mixture in a small crucible and cover it with 30 times its weight of litharge. That the mixture may not boil over, the crucible should be only half full. Cover the crucible, and heat gradually in a muffle or wind furnace to red heat. If the heat is raised too rapidly, combustible gases escape, or the mass may boil over. In using a wind furnace, the

crucible should be placed on a firebrick resting on the grate bars supporting the glowing coals. Shake coals around it until only the top of the crucible protrudes.

When the mass, which at first swells up, is fused, cover the crucible entirely with coals, and increase the heat for ten minutes to collect the lead in a button and then take it out. The whole operation lasts from 45 to 60 minutes. Break up the crucible, clean the button from adhering lead oxide by means of a brush, and weigh. To obtain a reliable average, from two to four tests must be made. As unity we refer to carbon, which reduces 34 times its weight of lead. The calorific power of carbon is 8,086 French heat-units*; every part of lead produced in the button $= \frac{8,086}{34} =$ 238 heat units. This result multiplied by the weight of the lead button, in grammes, gives the heat units contained in the coal. This result is not absolutely correct, but at most is only one-tenth too low, and is closer the higher the percentage of carbon in the coal.

It must be borne in mind that the result is the amount of heat, not the intensity, as that depends on the rate of combustion.

1442. Coking Coal.—As was stated before, the only positive manner of testing a coal for coking properties is a practical test ; but among some coals of the eastern side of the Appalachian field there is a ratio between the hydrocarbons and fixed carbon, which enables a fair conclusion to be drawn as to their coking qualities. The coals of the western side contain too much bituminous matter to make very good coke. For this reason, but a small amount of coke is made in the pitchy coal fields of Ohio, Indiana, and Illinois.

The Colorado, Wyoming, Montana, New Mexico, and other Western, or Northwestern and Southwestern, coals belong to the Trio-Jurassic and Laramie-Cretaceous

* A French unit of heat is equal to 3.96832 British thermal units, or, in other words, one French unit of heat will raise the temperature of 1 kilogramme of water 1.8° Fahr.

measures, and are independent of the ratio just mentioned. Some of these coals coke readily in the common bee-hive oven, while on the other hand a large portion of them, very high in hydrogenous matter, can not be coked.

Sometimes coals that will not coke in any oven will yield a splendid coke if a proper proportion of pitch is mixed with them.

It is becoming more evident daily that the property of coking is dependent upon the relation and volume of the elements composing the volatile combustible matter.

The prospector may well bear in mind that the moisture, fixed carbon, ash, and sulphur may differ widely without seriously affecting the coking properties. This is most conspicuously shown in the very large difference existing in the volume of carbon and ash in the Connellsville and the Pocahontas coals. Connellsville coal contains 59.79% of fixed carbon, while Pocahontas contains 72.70% of fixed carbon. The ash exerts no influence on the fusing of these coals in coking. Neither does sulphur nor phosphorus; both are simply undesirable in metallurgical coke.

As a unit of carbon affords 8,086 calories of heat, while a unit of hydrogen affords 34,462, coals low in volatile combustible matter must surrender in the ordinary oven an increased volume of carbon to compensate for the deficiency in the reduction of the greater heat giving hydrogen. In other words, heat required for coking, not supplied by the volatile matters, must come from the fixed carbon. This is seen in the fact that Pocahontas coal loses 20% of carbon in coking, while Connellsville coal loses only 8% of carbon in coking. The table of Coking and Non-Coking Coals in the Tables and Formulas may, in connection with the table of Analyses of Coal, be of advantage to the prospector.

1443. Specific Gravity.—To find the specific gravity of any body heavier than water, take a small cuboidal piece of the material suspended by a hair, weigh it in air, then in water; find the difference in weight. This difference is what the body loses in weight in water, and is the

weight of a bulk of water equal to the bulk of the body. Diff. of weights: Weight in air :: 1 : x, or

$$\frac{\text{Weight in air}}{\text{Difference}} = \text{specific gravity of body.}$$

EXAMPLE.—A piece of coal weighs 480 grains in the air and weighs 398 grains less in water. What is the specific gravity?

SOLUTION.—$\frac{480 \text{ grains}}{398 \text{ grains}} = 1.206$ specific gravity. Ans.

1444. Weight of Coal.—A cubic foot of water weighs 62.355 lb., and this 62.355 lb., multiplied by the specific gravity of coal, gives its weight per cubic foot. Thus, $62.355 \times 1.206 = 75.2$ lb. per cu. foot, when the specific gravity of coal is 1.206.

1445. Tonnage per Acre.—The number of tons of coal in any tract of land may be calculated by finding the number of cubic feet and multiplying it by the weight of a cubic foot in lb., and dividing the product by 2,240 for long tons, and 2,000 for short tons.

EXAMPLE.—How many tons are in an acre if the coal is 20 inches thick and the specific gravity is 1.206?

SOLUTION.—One acre = 43,560 sq. ft.

20" thick = $1\frac{8}{12}$ or $1\frac{2}{3}$ feet.

$43,560 \times 1\frac{2}{3} = 72,600$ cu. ft.

As was stated above, coal having a specific gravity of 1.206 weighs 75.2 lb. per cu. ft.; therefore, $72,600 \times 75.2$ lb. $= 5,459,520$ lb., and $\frac{5,459,520 \text{ lb.}}{2,000 \text{ lb.}} = 2,729.8$ short tons per acre. Ans.

A very convenient manner of making such a calculation is that used by Scotch mining engineers when checking the reported tonnage of the operator to the proprietor of the estate.

The specific gravity is found, the decimal point is removed, and the figure 1 is annexed; this gives the tonnage per inch per acre with due allowance for faults, wants, etc.

EXAMPLE.—How many tons of coal are in an acre, the coal being 3 feet thick and specific gravity 1.3?

SOLUTION.—Specific gravity being 1.3, the number of tons per inch per acre will be 131.

131 tons $\times$ 3 (feet) $\times$ 12 (inches) = 4,716 tons per acre. Ans.

LOCATION OF OPENINGS.

1446. Prospecting Party.—This should never consist of less than the leader and two laborers. It is often necessary and nearly always advantageous to have from 4 to 10 laborers in the party.

1447. Tools.—If the prospecting is to be done at a location remote from a town, in addition to the camping, surveying, and chemical outfit, there should be a pickax and shovel for each laborer, two axes, and one or two sets of drilling tools—jumper, hammer, scraper, needle, etc., and explosives. Also a wheelbarrow or two, hatchet, adz, nails, etc.

The prospector himself must have the following with him while in the field: 1. A pocket compass, with which to ascertain the direction of any line of outcrop, dip, fault, etc. 2. A clinometer for the purpose of noting the angle of inclination of exposed strata. 3. A small hammer with a chisel-shaped head at one end, similar to Fig. 416 (this chisel-edge enables him to conveniently split finely laminated shales or slates). 4. A small bottle containing a weak solution of hydrochloric acid, for the purpose of testing carbonates (on applying this acid to limestone it effervesces). 5. A note book and pencil.

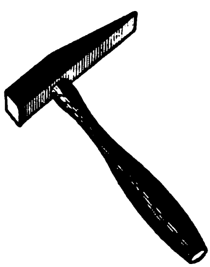


FIG. 416.

1448. Location of Permanent Openings.—The place or spot at which the mine openings should be located will be largely indicated by the data laid down on the complete map. This will show the extent of the property, whether the coal crops out within the boundary lines or not, the roads, railroads, canals, rivers, and the general configuration of the surface, important faults, etc.

In mountainous regions where the coal lies in conical hills, it is evident that the railway must follow mostly the direction of the valley, and in such cases where the coal

crops out within the limits of the property and the seam is flat, the opening is best made by a drift or day level (Fig. 417) at such a point as can be readily reached by a spur

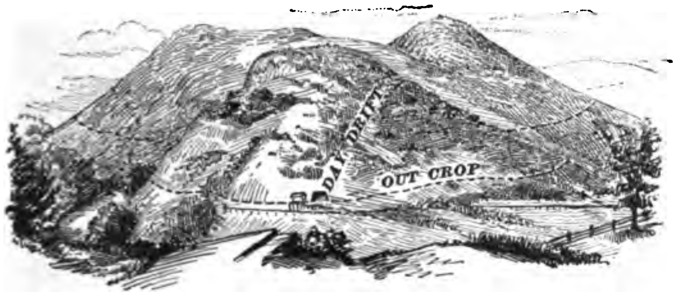


FIG. 417.

from the railroad. If the coal has any considerable dip and outcrops on the property where the railroad can reach it, it should be opened by a slope driven in the coal. When the pitch is very great, say 40° or over, and the area of coal above the point at which a level tunnel or stone drift will strike the coal will guarantee the outlay of capital, the "stone drift" driven "across the measures," or strata having a slight rise inwards, may be adopted. These stone drifts under such conditions are very rarely undertaken on account of the great expense. Where the measures are flat

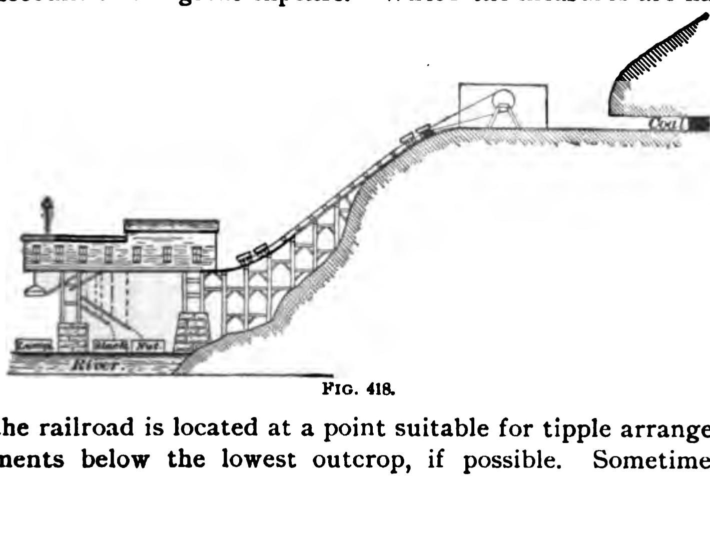


FIG. 418.

the railroad is located at a point suitable for tipple arrangements below the lowest outcrop, if possible. Sometimes

the coal is at such a height above the railroad or waterway that a self-acting incline must be used to lower the coal to the tipple (Fig. 418). At many mines a number of seams are worked simultaneously, the coal being lowered to the tipple by self-acting inclines. There are many cases where the coal does not crop out on the property, or the outcrop can not be reached by the railway. If the coal has no outcrop on the property, a stone slope or a shaft must be sunk. At vertical depths not exceeding 200 feet, "stone slopes" (pitching about 14°) are in great favor with some mining engineers. If the coal crops out at a point below the railroad, as it often does, an engine plane is built which carries

FIG. 419.

the coal to the summit, and in many cases the coal is again lowered by self-acting inclines to the tipple, which is in a valley at an elevation less than the high ridge over which the coal is hauled, but high above the level of the coal seam (Fig. 419).

1449. In a district where the coal measures are flat and there is no outcrop, excepting where rivers have cut a channel deep enough to divide the coal seam, an incline is run down a dry channel to the outcrop up which incline the coal is hauled from a great number of drifts (producing sometimes over 2,000 tons per day), whose length may be several miles, if mechanical haulage is employed, to the railroad above. But it often happens that in spite of every

precaution in some seams the main hauling roads can be maintained only to a limited extent, and to reach the coal beyond this limit no other course is open but to sink shafts close enough together to each other so that the limit of the entries or gangways from each shaft or drift will meet, ensuring, as nearly as possible, the extraction of all the coal.

1450. When the dip of the valley in which the coal crops out is equal to or greater than the dip of the coal and in the same direction, as a matter of course, if the railway or even a tramway can be readily built to the opening it should be made at the lowest point of the area it is to supply the outlet for, to ensure a favorable mule haulage and good self-drainage. In some districts the coal is so undulating and irregular that drainage and haulage have no weight in deciding upon the position of the location. The object

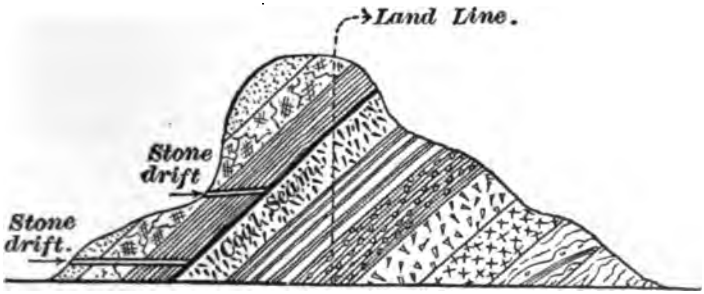


FIG. 420.

here to be considered is a suitable site for hauling and pumping machinery. When the seam has a heavy pitch inwards and the hills are high, a "day drift" or level may be located in a ravine or gulch eroded across the strike (see Fig. 420), and the coal can be reached by a short "tunnel" or "stone drift," from which the coal lying above it can be mined. If the length above the drift is less than 200 feet to 300 feet, a slope had better be started at once.

1451. When the seam has considerable dip and is brought close to the surface by an anticlinal axis, a "rock slope" dipping at the same angle as the seam may be started

from the surface (*A*, Fig. 396), and when the coal is reached it may be carried in the coal to any practical length. Where the coal crops out it is customary to drive an airway parallel with the slope, leaving the pillar required by law between. But where the coal turns on the axis before reaching the surface and a "rock slope" is driven, as just described, the parallel slope is driven only in the coal and a shaft sunk at the axis to the coal for an airway.

When the coal lies more than 200 feet below the surface (where the rocks have been metamorphosed, much less than 200′), in rocks of moderate texture, no other method of reaching the coal except shaft sinking is worthy of consideration. When the top rock is such that long roads will stand without an undue amount of care and expense, the openings should be made with a view to concentrating the work of a large output in one opening. A number of shafts create very great expense, not only in sinking, but for engines, pumps, tipples, spur tracks from railroad, etc. Further, the number of day hands does not vary directly as the output, that is, a larger number of day hands as a rule will be required to handle 400 tons per day from each of two pits than will be required to handle 800 tons per day from one pit. The opening must also be located, if the seam is inclined, so that most of the field will be to the rise of the pit bottom, so that haulage and drainage may be facilitated. In other words, other things being equal, the site which gives the largest amount of field to be worked to the rise is preferable. Surface conditions sometimes outweigh underground considerations.

1452. In a new field it is never desirable to make the first shaft the permanent one, or the most important one. The permanent shaft may be better located later on, when more detailed knowledge of the district has been obtained.

When the seam underlies a great tract to such an extent that it can not be reached by a drift from the outcrop, or when there is no outcrop, and the coal can not be hauled through one or two shafts, the surface configuration permitting, shafts should be located systematically with regard

both to the area of the field and the area for which each shaft will be the outlet. In order to accomplish this it will be best to wait until the extent to which the workings of the first shaft can be profitably extended, mechanical haulage considered, is determined. The demand for a very large tonnage early in the history of the field sometimes requires more than one shaft at once, in which case the best location must be selected that is indicated by the information on the map.

Quicksands may modify the arrangements, as may also great quantities of water, but never to any great extent in these days of improved facilities for sinking.

Slopes, up to the present time, have been and still are greatly preferred to shaft openings at all points in the anthracite regions of Pennsylvania, where the coal is accessible along its outcrop and where the dip is more than 15° or 20°.

In the bituminous region of Pennsylvania and many of the Western States shafts of moderate depth are common.

As many outcropping seams have a slight inward dip, to ensure a long level haulage road and good water drainage, the opening is commenced several feet below the terrace, and driven level, or on a very slight up grade, until the normal dip is reached. It sometimes happens that the inward dip is so strong that it is advisable to open by a shaft sunk in the center of the basin, provided the depth is not too great and the amount of water small. When the inward dip to the center of the basin does not exceed about 24′ or 26′, drainage may be accomplished through a drift, by siphon, the pipes being of the diameter required to remove the water.

SHAFTS, SLOPES, AND DRIFTS.

INTRODUCTORY.

1453. The method of opening out a coal field will depend entirely upon its physical and geological characteristics and upon its position with regard to railroads, rivers, and canals. When a seam of coal lies comparatively flat and is covered by a shallow depth of strata, it is "stripped," and the coal is obtained in much the same manner as building stone is taken from the quarry.

Such easily accessible coal is soon worked out, necessitating other methods of reaching deep-seated seams. Where the seam lies at a considerable depth from the surface, and more especially where it lies flat or nearly so, it is usual and advisable to sink a shaft to win the mineral. If

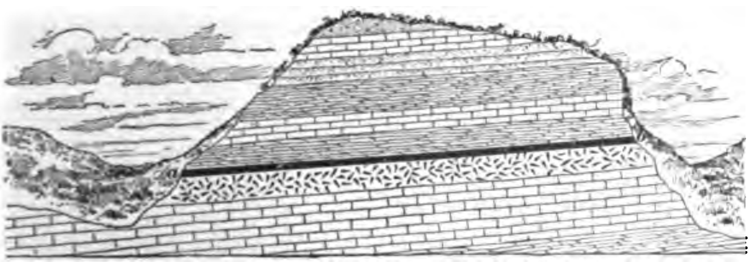


FIG. 421.

the coal lies above water level and nearly flat, as in some parts of the bituminous districts of Pennsylvania, it is most convenient to open it out by means of a "water-level drift." For instance, in the case of a seam of coal lying in a mountain, as shown in section in Fig. 421, the most convenient place to enter the seam would be at *a*, which is the lowest part of the seam, because the water would naturally drain that way and no expense would be incurred for pumping,

the loaded cars would have the advantage of the down grade, and there would be no need to sink a shaft to win the coal.

1454. In the case of a seam of coal lying at a considerable dip, and having its outcrop on the side of a hill, as at *a* in Fig. 422, the seam can be opened out in three different ways: 1. A slope can be driven in the seam from *a* to *b*, and the coal drawn and water pumped up the slope. This sys-

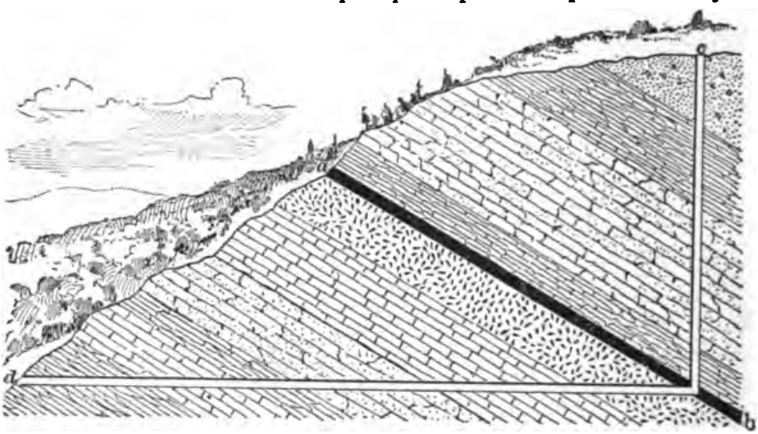


FIG. 422.

tem would have the advantage of enabling the coal field to be more rapidly opened out by means of levels, gangways, or benches turned off at intervals to the right and left of the slope as it is being driven down towards *b*. 2. The coal can be won by a shaft sunk to *b* from the surface at *c*. 3. A tunnel can be driven to *b* from a point *d* on the hillside. This tunnel will have the advantage of a dip towards *d* whereby the entire coal field can be drained by gravitation without any expense for pumping machinery. The haulage can also be done cheaply for the same reason. The decision as to whether the shaft *c b* or the tunnel *d b* will be preferable depends on at least two conditions. If the seam lies somewhat flat, a shaft will be preferable, because a shallow shaft will reach the greater area of coal; but if the seam is more than 45° from the horizontal, then a tunnel will be preferable.

The cost per yard for tunnel driving is very much less than the cost per yard for sinking a shaft, but in the majority of coal fields the seams have a moderate dip, and a tunnel in most cases to win a large area of coal will be very long. The great distance the coal must be hauled, the first cost and maintenance of roads, of long haulage ropes, and the wages and material necessary to maintain this long tunnel will more than cover the cost and maintenance of a shallow shaft to win the same area of coal. The main consideration, however, will be whether a shaft from the top of the hill or a tunnel on the hillside will provide the most convenient point of delivery for the coal.

SHAFTS.

LOCATION OF SHAFTS.

1455. Having decided that it is best to open up a coal field by a shaft, the next thing to be done is to determine its location. This must be done with extreme care, for the degree to which the important problems of haulage and drainage may be simplified and the entire operation made a commercial success will depend largely upon where the shaft is situated.

Perhaps there is no other point in the development of coal lands where more errors have been made than in selecting sites for shafts at new collieries. Every fact obtained by thoroughly prospecting the field and investigating the means of transportation should have special attention in fixing the location of the shaft.

1456. The shaft should be located to suit:

1. Underground conditions.
2. Surface conditions.

As all the coal mined in the property must be brought to the foot of the hoisting shaft, care must be taken to have the shaft so located that the mine cars can be conveyed to it with the least possible expenditure of labor. This advantage can be secured by sinking the shaft in the basin or

lowest point of the coal field, so that the loaded cars will have a down grade from all sides to the shaft bottom. This is also the most convenient place to erect the pumping plant, as the entire field can be drained from this one point. It must also be remembered, however, that, owing to the enormous expense in sinking shafts, the fewer shafts that must be sunk the better, and the shaft should be so located as to command the greatest area of coal. For this purpose, and more especially with a flat seam, the best position for the shaft is in the middle of the coal field, so that gangways or main entries can be opened out on all sides of the shaft.

In considering the surface conditions affecting the position of the shaft, attention must be paid to the railroad, river, or canal connections. For instance, the railroad may pass through that end of the property where the coal is nearest the surface; and it is then a matter of calculation of cost whether the shaft shall be sunk at the dip end of the field and a branch railroad run across the property, or whether it shall be sunk beside the railroad to save siding expenses. The latter requires more underground haulage to deliver the coal to the foot of the shaft.

The configuration of the surface, the existence of hills, towns, and obstacles of all sorts will influence the engineer in fixing the position of the shaft.

Another condition sometimes requires consideration, namely, the existence of large deposits of surface soil or running sand or gravel. If the shaft can be sunk so as to avoid these, it should be done, as the cost of sinking through a bed of running sand is sometimes enormous. The existence of faults often influences the selection of the site.

FORMS OF SHAFTS.

RELATIVE ADVANTAGES OF DIFFERENT FORMS.

1457. There are various forms in which shafts are sunk—circular, square, oblong or rectangular, elliptical or oval, and polygonal.

Generally speaking, the circular shaft is the most secure and the rectangular form least so, and for equal areas the

former requires less "wall cutting" and timber than the latter.

But, while a saving of labor and of materials is thus secured, it does not follow that a manager in America should throw aside the usual rectangular form in favor of the circular one. Aside from the fact that the rectangular shaft is more common, and the workmen are more familiar with it, a circular shaft requires greater skill in timbering or walling, and the timbering or walling itself is of a more expensive kind. The divisions of a rectangular shaft are readily put in, and there is no waste of area as in most circular shafts. In cases presenting few difficulties and in view of the men being more familiar with the rectangular form of shaft, it is more economical, and really better, except where deep sand beds and very large feeders of water are met with. In the latter case, a circular shaft with its greater strength and facility for tubbing is better.

1458. The size of any shaft depends upon the use to which it is to be put. In any case, a very "tight fitting" shaft is extremely troublesome, and the increased first cost to secure a little more room is certainly repaid by a greater facility for getting work done, and is particularly advantageous for pumping and ventilation purposes.

Several of the coal-mining States have laws preventing single openings, but there are practically no restrictions as to the purposes for which shafts may be used. Hence, one shaft may be used for hoisting, ventilating, and pumping, or it may be used for hoisting and pumping, and the second one may be used for ventilating and as an escape for the workmen.

RECTANGULAR SHAFTS.

1459. No fixed rule can be given for calculating the size of a rectangular or any other form of shaft. The size is governed by the conditions already mentioned; also by the average hoisting speed, the depth of the shaft, and the thickness of the coal seam, all of which in a manner determine the size of the mine car.

The speed of hoisting the output may vary from 24,000 feet per hour to 40,000 feet, or more, per hour, including the time taken up in charging and discharging at top and bottom.

By deciding upon the required tonnage, the probable depth of the shaft to reach the seam, and the desired output speed, the following rule may be used to find the length of the winding compartments:

Let S = output speed;
D = depth of shaft;
T = tonnage expressed in pounds;
N = number of working hours;
W = weight of a cubic foot of broken coal;
B = average inside width of car;
d = inside depth of car;
L = length of compartment;
f = clearance in shaft at ends of cage = 1 foot.

Then, $$L = \frac{T\,D}{S\,N\,W\,B\,d} + f, \qquad \textbf{(85.)}$$

that is, the length of the compartment equals the tonnage in pounds times the depth of the shaft divided by the continued product of the output speed in feet per hour, the number of working hours, the weight of the coal per cubic foot, the width of the car, and the depth of the car plus the clearance.

EXAMPLE.—Tonnage, 960; number of working hours, 10; depth of shaft, 500 feet; weight of a cubic foot of broken bituminous coal, 50 lb.; output speed, 30,000 feet per hour; average inside width of car, 4 feet; inside depth of car, 3 feet. What is the length of the compartment?

SOLUTION.—

$$L = \frac{960 \times 2{,}000 \times 500}{30{,}000 \times 10 \times 50 \times 4 \times 3} + 1 = 6 \text{ feet 4 inches in the clear. Ans.}$$

1460. The width of the compartment is yet to be determined. The average width of the car may be 4 feet, but it may be flared to 5 feet at the top, so that the cage will have to be 5 feet plus the clearance on each side of the car—say 3 inches on each side—making it 5 feet 6 inches.

Add to this the width of the angle iron and shoe used in constructing the cage—say 6 inches on each side—making 5 feet 6 inches + 1 foot = 6 feet 6 inches. The conductors, or guides, if of wood, may be from 4 to 6 inches thick—in this case say 4 inches each, and there are two of them—making 6 feet 6 inches + 8 inches = 7 feet 2 inches as the width of the compartment in the clear. In calculating the total length of the shaft, if there are two hoisting compartments and a pumpway, twice the width of the hoisting compartment in the clear plus the width of the two buntons plus the width of the pumping compartment in the clear, equals the total length of the shaft in the clear.

Thus,

$$\begin{pmatrix}\text{compartments}\\ 7'\ 2'' \times 2\end{pmatrix} + \begin{pmatrix}\text{two buntons}\\ 1'\ 4''\end{pmatrix} + \begin{pmatrix}\text{pumpway}\\ 6'\ 0''\end{pmatrix} = 21'\ 8''.$$

The shaft will, therefore, be 21 feet 8 inches by 6 feet 4 inches in the clear.

This calculation may be modified in various ways. For instance, the tonnage may be nearly doubled under exactly the existing conditions if a double-deck cage is used; or, with the same speed and length of cage, the tonnage be doubled by lengthening the shaft so that two cars can stand side by side on each cage; or the length of the cage may be such that two cars can stand tandem; or these various conditions may be combined on a single-deck cage, and four times the original tonnage hoisted at the same speed. The tonnage may be increased, without enlarging the cage, by increasing the output speed. These statements do not take into consideration the power of the engine, which will have to be strong enough to start the load and hoist it at a sufficient speed.

1461. When the size of the shaft has been determined, the next thing in order is to consider the position of the sides of the shaft in relation to the dip of the seam. The long side of the shaft should be as nearly as possible parallel with the line of the dip. When the ends of a cage are in line with the strike of the seam, the charging of the cages

below ground can be most economically accomplished. This arrangement may not suit the railroad on the surface, but it is better to make the shaft bottom right and place the chutes to suit the railroad.

1462. It is necessary to consider beforehand the probable depth to be sunk, and to arrange the location of the engines and machinery which are to be permanently used for winding. The manager should provide a proper supply of tools, such as picks, drills, hammers, wedges, shovels, barrels, etc., and he should anticipate the supply of materials that will be required in the prosecution of the work. The work of sinking should be done by experienced men.

If the permanent engine is not ready for work, sinking may be commenced without it, and the material may be hoisted out of the shaft by a portable engine or horse gin The pit may be sunk to the depth of sixty feet by the aid of a windlass.

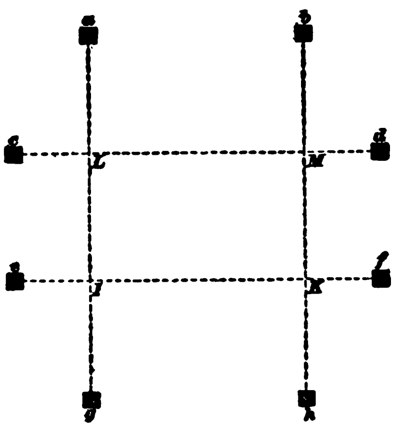


Fig. 423.

Before commencing to sink, it is necessary to set stakes marking the location and position of the shaft. The stakes should be set on line with the sides of the shaft and beyond the limit of excavation, so that they will not be disturbed by the workmen.

1463. The work of sinking is commenced by setting sight stakes *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, Fig. 423, and stretching lines from them as shown. The rectangle *I K L M* marks the outline of the shaft, and must be of such dimensions as to include the outer side of the shaft timbering or walling, as the case may be. It is generally advisable to place a similar set of stakes on the same lines and back still farther

from the shaft. In case anything happens to the inner stakes the outer ones can be used to reset them. The outer stakes should be driven below the surface and their approximate location marked with a stake or stone so they can easily be found. Sometimes surface conditions exist which make it desirable to wall the upper part of the shaft with stone. In such a case the outside cribbing consists of timbers, shown at *a*, *a*, Fig. 424, and lining plant *b*, *b*. The timbers *a*, *a* may be

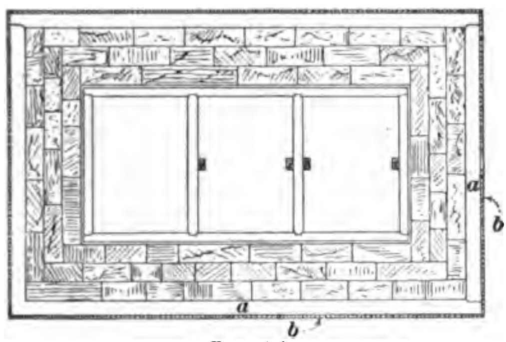


FIG. 424.

12″ × 12″. Each set is placed from one foot to four feet, or more, apart, according to the looseness of the ground sunk through, and held in position by punch blocks *B*, Fig. 425.

1464. The sinking should be carried far enough into the stratum, or "hard pan," to ensure a solid foundation for the stone wall. If there is much water, the outside timbering should be removed as the wall is built up, and its place filled with clay, well rammed, to keep back the water. This part of the shaft is then completed, the buntons being put in as the walling is carried upwards. If it is desirable to carry the regular timbering clear to the surface, instead of building the buntons into the walling, the walling must set back far enough for the regular timbering to be put in.

1465. Figs. 424 and 425 show the walling and timbering of a rectangular shaft. It is necessary to timber only where the material sunk through will not stand, or where it is necessary to dam back feeders of water.

A set of timbers for a shaft of three compartments usually consists of :

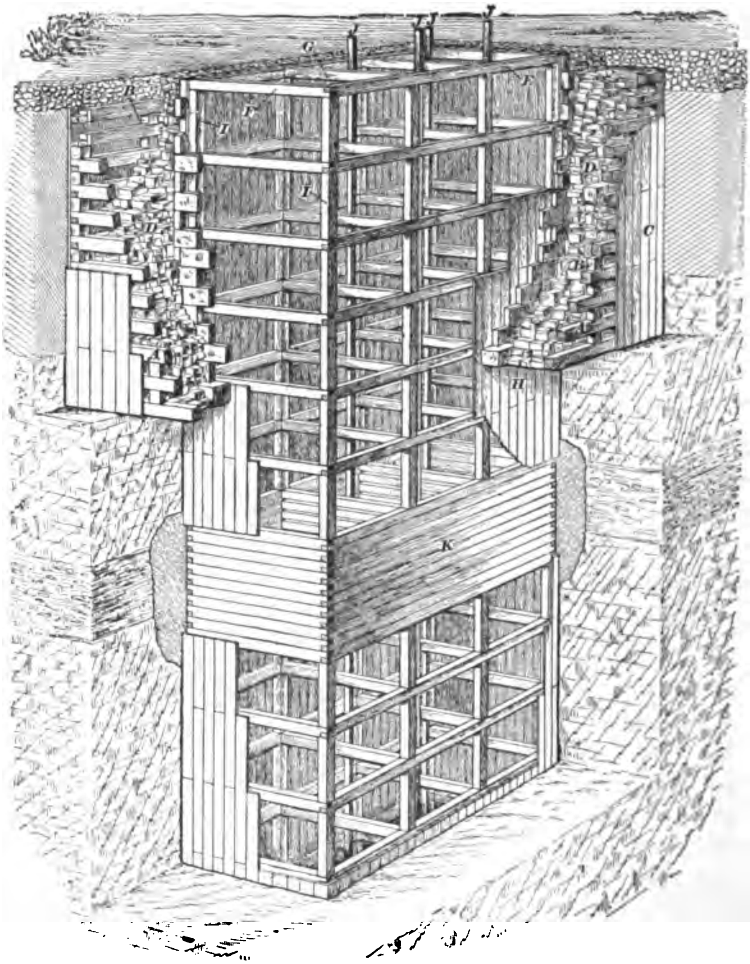


FIG. 425.

1. 2 side pieces, 10″ × 10″ × — feet.
2. 2 end-pieces, 10″ × 10″ × — feet.
3. 2 buntons, 10″ × 10″ × — feet.
4. Sufficient 2 or 3 inch plank to go around the shaft for

lining between the timbers. (See *H*, Fig. 425.) These timbers may be made of pine, or any other durable wood that can most readily be secured. They are kept apart by punch blocks *I*, Fig. 425.

1466. When strata of a wet nature are encountered, it is necessary to put in a cofferdam built of masonry or of timber that is placed close together, putting in a tar cloth joint, and bolting the timbers together, or, better still, by mortising one set into the other, so as to form a thoroughly water-tight joint. Such a dam is shown at *K*, Fig. 425.

After the masonry has been built up a foot or two, or one or two sets of timber have been put in, the space between the back of the walling, or timbering, and the strata is filled in with good loamy soil or clay, which should be free from pebbles and should be carefully rammed. Then two more sets are put in and the space filled and rammed in the same manner, and so on till the water-leaking strata are completely closed in and no water appears.

A perspective view of the shaft lining, masonry walling, and cofferdam is given in Fig. 425. In this view, *A* shows the temporary side and end timbers, *B* the punch blocks, and *C* the outer lining put in to go through the soft ground. The masonry is shown at *D*.

The permanent timbers are shown as follows: *E*, side timbers; *F*, end timbers; *G*, buntons; *H*, lining; *I*, punch blocks; *J*, *J*, *J*, *J*, guide rods; *K*, cofferdam.

1467. When a shaft reaches hard rock no timbering is needed excepting the guides, or conductors, and buntons for carrying water pipes and guide rods. These buntons are set in the solid rock and wedged tightly in vertical lines, so that the conductors when bolted to them will be plumb. Even when there are no other timbers in a shaft of three compartments, there must be at least four buntons on the same level every six or eight feet for carrying the conductors. When pipes are put in, five or more buntons will be required.

1468. If, after the shaft has penetrated the hard strata for some distance, a slight feeder of water is met which can not very well be dammed back, or the water-bearing stratum is very thick and the water only percolates through it into the shaft, the cost of a cofferdam prohibits its use. A "water ring" is then made by widening the shaft at *a*, Fig. 426, and again contracting it at *b*.

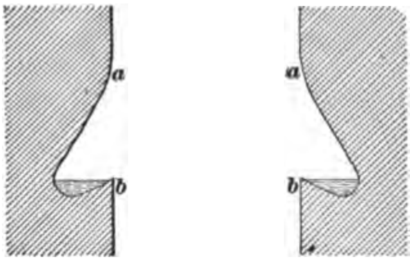


FIG. 426.

The water may be conducted from this "water ring" in pipes to a sump at the shaft bottom.

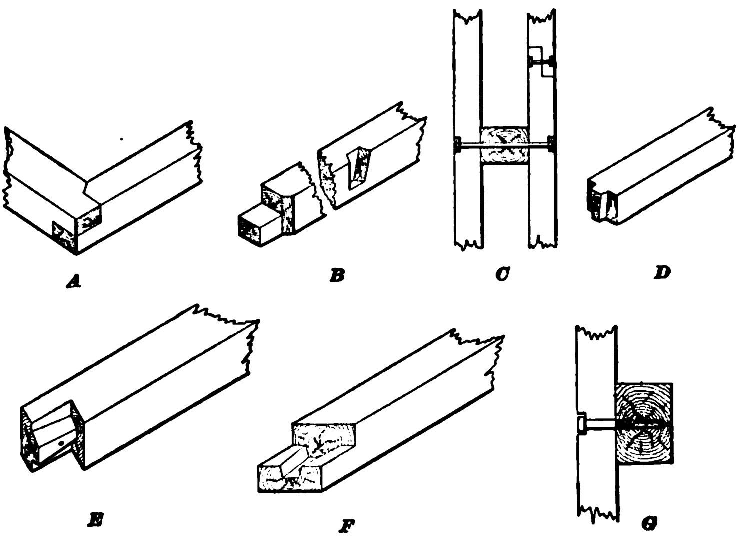


FIG. 427.

1469. Fig. 427 illustrates all the joints used in fitting the shaft timbers together.

A shows the joint of end and side timbers.

B shows the side timber joint and also the dovetailed mortise to receive the dovetailed tenon of bunton *D*.

D shows the dovetailed tenon to fit in dovetailed mortise shown in *B*.

E and *F* show the method of jointing the guides, or conductors.

C shows the manner of bolting *E* and *F* together, and also shows how guides, or conductors, are bolted to the buntons.

G shows the guide fastened to the side with a large screw, countersunk, as it is impossible to get behind the timbers when putting in the guides to screw up a nut on a bolt.

There are many other forms of joints, but those given are the best known, and should be used.

1470. A plan of the shaft mouth showing carriage

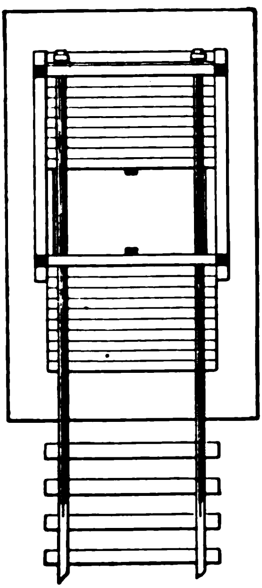


FIG. 428.

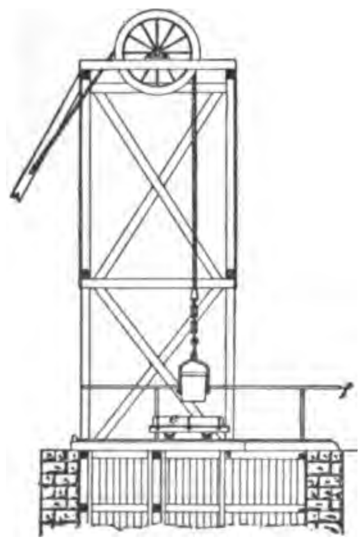


FIG. 429.

track and derrick is given in Fig. 428. In Fig. 429 the

temporary hoisting arrangements for sinking are shown at the opposite end of the shaft from the pumpway. This is to allow the permanent winding machinery at the side of the shaft and the permanent pumping arrangement at the pump end to be erected while the sinking is progressing, if they have not been erected before beginning to sink. The temporary head-frame, or derrick, is so placed that all the hoisting takes place in the middle compartment, in order to equalize the distance the sinkers must move the excavated material to get it into the bucket, bowk, kettle, or kibble, *C*, Fig. 430.

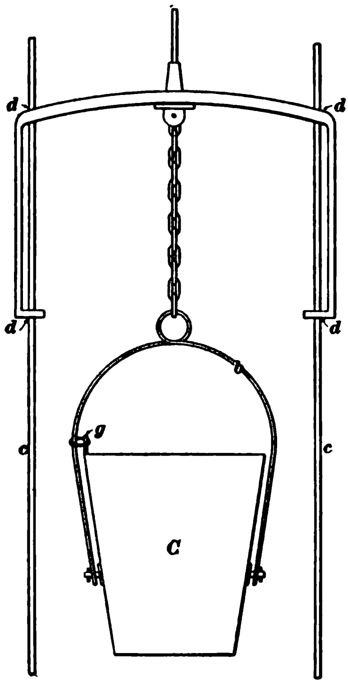


FIG. 430.

1471. The two ends of the shaft are covered with strong planking at the shaft mouth. (See Fig. 428.) At one side of the shaft there should be an opening under the platform to assist ventilation. If this is not practicable, a board stack can be erected over the end of the shaft farthest from the dump. A large car *c*, Fig. 429, running on rails, is placed at the top of the shaft so that it can be run across the part of the shaft mouth which is open, and thus entirely close the top of the shaft, so that when the bucket is being emptied there will be little danger of any pieces, no matter how small, falling on the sinkers below. The excavated material is filled into a bucket and hoisted to the surface. When the bucket reaches the surface, the topman, headman, or banksman catches the guard-rail *f*, and, standing in the car, pushes it over the mouth of the shaft. The bucket which

is permanently fastened to the rope by the wrought-iron bow *s* is now lowered, emptied into this car, and again raised into position ready for lowering into the shaft. The car is now run back from the mouth of the shaft, and the rock, etc., unloaded.

The wrought-iron bow *b* (Fig. 430) of the bucket is attached to it at a point below the center of gravity, so that when full the tendency is for the bucket to turn over and empty itself. To prevent this while hoisting, a short vertical pin *g* is riveted to the side of the bucket, and an ordinary chain link sliding on one arm of the bow passes over it.

1472. Covering the mouth of the shaft with a traveling car while sinking is open to a great number of objections, to overcome which the arrangement of levers and counterbalances shown in Fig. 431 may be used.

Each door is bolted to two hinges *d*, *d*, which are keyed

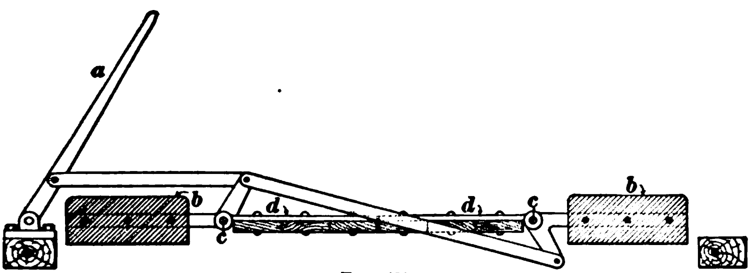


FIG 431.

on shafts *c*, *c*. By means of the handle *a*, and the connecting arms, a rotary movement is given and the doors lift as the lever is pulled back. The weight of the doors is counterbalanced by four blocks *b*, *b*, so that they will stand at any position desired.

1473. Sinking Guides.—The oscillation of the bucket in deep sinking becomes very great, and much time is lost in steadying the bucket before it starts upwards. The best method to overcome this is shown in Fig. 430. The guide ropes *c*, *c* are coiled on a drum at the surface so that they can be lengthened as the sinking advances. These ropes

have large weights attached to their lower ends in the shaft to keep them steady. An iron frame, called the **rider,** consisting of two legs joined together by a cross-bar, clasps the two guides loosely at the four points *d*. The winding rope passes through a hole in the center of the rider.

Sometimes the permanent guides are put in at the same time the shaft timbers are placed, in which case the ropes *c*, *c*, Fig. 430, are not required.

1474. The shaft sinking is continued, with or without timber, as the strength of the strata may require, far enough below the coal to make a "lodgment" for the water. The size should be the same as the section of the shaft, but the depth will depend upon the amount of water. When the seam has a considerable dip, a large lodgment can be made in it by excavating galleries to the dip of the shaft in the coal, and leaving a solid barrier all around to prevent the water making its way into the dip workings. The water is pumped from this lodgment through a slanting suction pipe, or a level tunnel connects the lowest point of the lodgment with the sump bottom, which is the continuation of the shaft.

1475. Shaft Ventilation.—This is accomplished by constructing a midwall between the pump and the hoisting compartments, which must be perfectly air-tight. This can best be made by putting up a double lining of selected tongued and grooved lumber, or well selected boards, placing a sheet of heavy tarred paper between the double lining. For the first few yards there is no difficulty in supplying air, provided the midwall closely follows the sinking, as the moving bucket creates a current. When this fails, the smoke may be driven out by pouring a barrel of water down the shaft, or by hanging a "fire lamp" temporarily within the shaft. When the less effective devices fail to produce the required ventilation, a steam jet may be used.

Chokedamp and firedamp are both found in sinking shafts, and the former has caused several fatalities at a shallow depth from the surface. The shaft should be carefully examined before the sinkers enter, especially when there is any interval between the shifts going off and coming on.

CIRCULAR SHAFTS.

1476. Circular shafts are rarely used in North America, yet there have been a few instances where the circumstances were such that the circular form was imperative, the most conspicuous being the Princess Pits, of Sydney Mines, Cape Breton, Nova Scotia. The winding shaft is 13 feet in diameter and 682 feet deep; the pumping shaft close by the winding shaft is 11 feet in diameter and 709 feet deep. There is also a staple, or auxiliary, pumping shaft 389 feet deep from the surface.

At the depth of about 200 feet, a feeder of water was met which was successfully overcome by pumping, but at a depth of 267 feet, water came in through fissures in the thick bed of sandstone directly from the sea. This had to be shut off by lining the shaft with cast-iron tubbing.

Fig. 432 shows a section of the shafts on a small scale, in which *d* is a cross-cut through which the water flows from pumps in shaft *C* to pumps in the staple shaft, and *e*, *f*, *g*, and *h* are cross-cuts made between the shafts to facilitate the process of sinking; these latter cross-cuts are closed off by the tubbing.

The tubbing plates for this kind of work are cast in segments of such length that the circumference is divided into equal parts, their height varying from 18 to 36 inches, according to the pressure to be resisted. A **closer,** which is a section of tubbing used to connect a lower stage of tubbing with the crib of the stage above, must generally be made an odd size.

Nine segments complete the circle in the *B* pit, or winding shaft (Fig. 432), eight segments in the *C* pit, or pumping shaft, and five segments in the staple pit, or auxiliary pumping shaft.

1477. The confinement of air and gas behind the tubbing may cause a water blast. No matter how thick the tubbing may be, a water blast will break it, or displace it from its seating. To guard against this in the shafts at Sydney, a 4-inch brass valve was placed in each crib at the

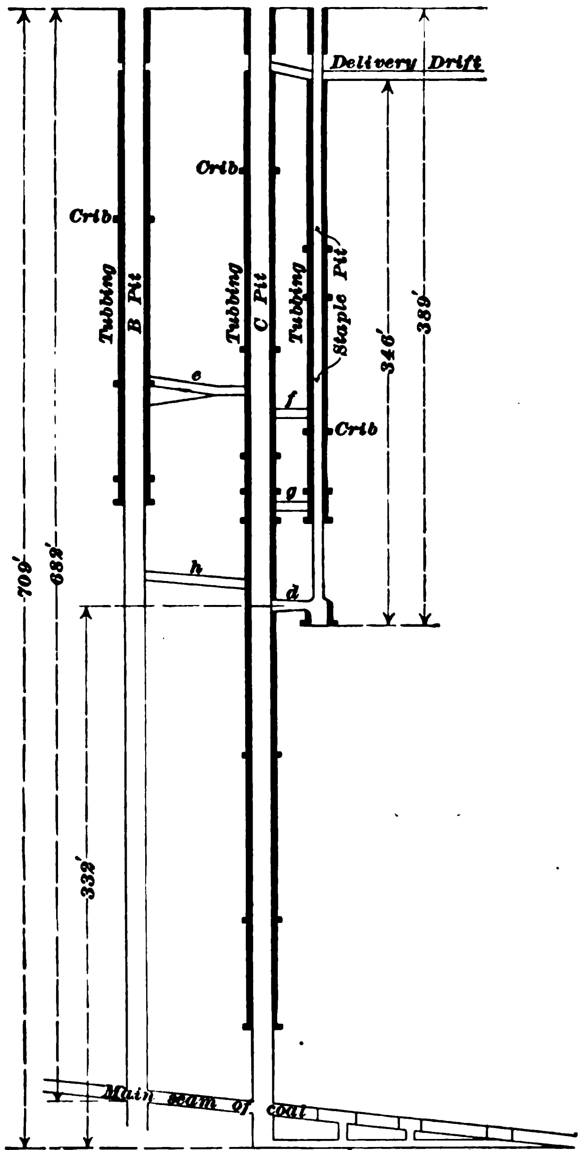

Delivery Drift
Crib
Crib
Tubbing
B Pit
Tubbing
C Pit
Tubbing
Staple Pit
346'
389'
e
f
Crib
g
h
d
709'
688'
332'
Main seam of coal
Underlevel Drift

FIG. 432.

back of the tubbing to allow the air to pass freely from the lowest to the highest lift. Also, each segment of tubbing had a hole of $1\frac{3}{4}$ inches diameter through its center (see section *a*, Fig. 433) to let the air escape during the process of wedging; these holes were plugged when the wedging of the joints was completed.

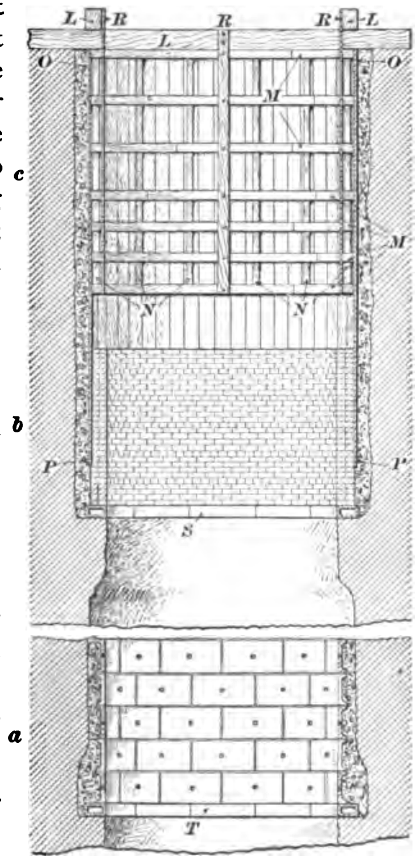


FIG. 433.

1478. A wedging curb in wet strata can only be located at a good hard stratum of rock, which must be dressed down with chisels and cut to a perfectly level and even surface. When the wedging curb or wedging crib of eight segments—more or less, as the case may be—is laid on the perfectly cut bed, and wedged up securely, the segments of tubbing are built upon it, breaking joints with each other as shown in section *a*, Fig. 433.

1479. The top and one of the side flanges of each segment are provided on the outside with a projecting ledge (4″ deep at Sydney mines) which keeps the joint sheathing and adjoining segments in position.

When the segments are being put in position, sheathing (usually pine ½ inch thick) is placed between both horizontal and vertical joints, and a wedge tightly driven down between

the back of the plate and the side of the strata to prevent any movement of the segments.

When a number of courses of tubbing have been set up in place, all joints are wedged up; that is, small wedges of red pine are inserted in the sheathing and driven in until the wood becomes compressed so hard that the chisel edge can not be driven into it.

The tubbing is put up in lifts or sections. A lift or section at Sydney mines consisted of a wedging curb and from five to fifty courses of tubbing built thereon.

1480. The following formula is used for calculating the proper thickness for cast-iron tubbing:

Let t = thickness of tubbing in inches;
d = diameter of shaft in feet;
D = depth in feet;
G = the crushing load of cast iron per square inch; usually taken at 90,000 pounds.

$$t = \frac{6\,d\sqrt{G} - 6\,d\sqrt{G - 6.944\,D}}{\sqrt{G - 6.944\,D}} \qquad \textbf{(86.)}$$

$$= \frac{1{,}800\,d - 6\,d\sqrt{90{,}000 - 6.944\,D}}{\sqrt{90{,}000 - 6.944\,D}}, \text{ when } G = 90{,}000.$$

The upper course of tubbing should in all cases be at least $\frac{1}{2}$ of an inch thick in the plate, even in shafts of very small diameter; and $\frac{5}{8}$ of an inch thick in shafts of large diameter, to prevent liability to fracture. It is also desirable to add a constant, usually $\frac{1}{8}$ of an inch, to the thickness obtained by the formula, to allow for wear and tear, and for corrosion or other chemical action on the metal.

In this formula, no allowance is made for the extra strength given the segments by the flanges and ribs. Theoretically, each set of segments should have a different thickness, but in practice they are calculated for every 25 or 30 feet.

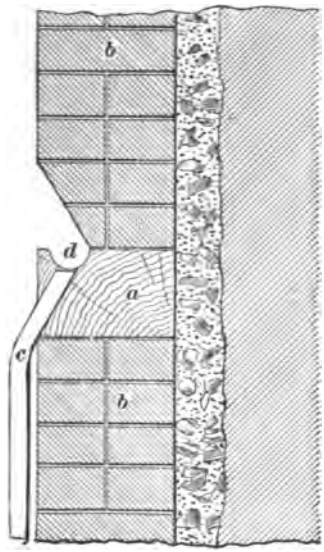


FIG. 434.

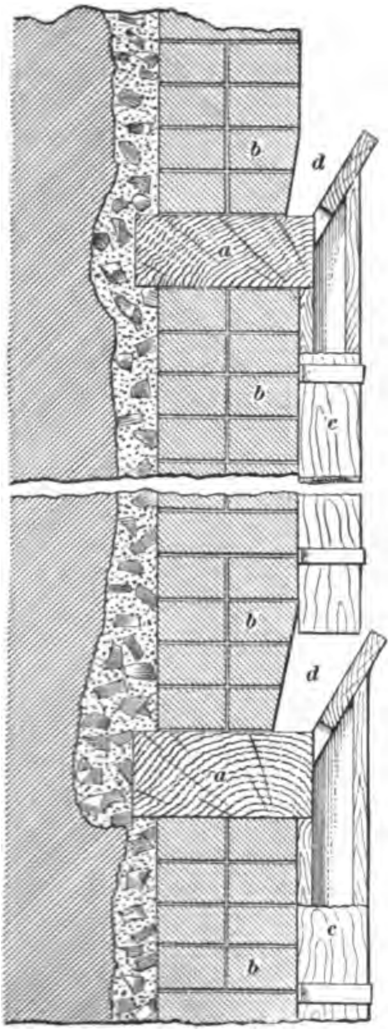


FIG. 435.

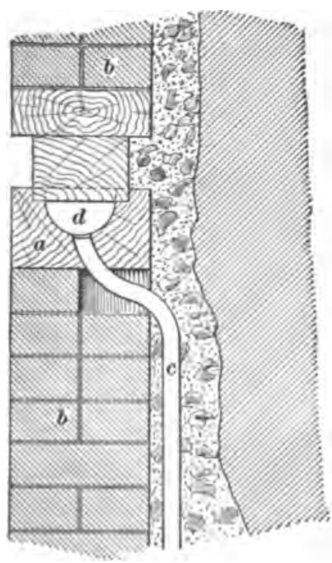


FIG. 436.

EXAMPLE.—What should be the thickness of cast-iron tubbing for a shaft 13 feet in diameter at a depth of 800 feet, allowing $\frac{1}{8}$ inch for rust?

SOLUTION.—By substituting these values in the preceding formula, we have

$$t = \frac{1{,}800 \times 13 - 6 \times 13\sqrt{90{,}000 - 6.944 \times 800}}{\sqrt{90{,}000 - 6.944 \times 800}}$$

$$= \frac{23{,}400 - 6 \times 13 \times 290.6}{290.6} = \frac{23{,}400 - 22{,}666.8}{290.6} = 2.523 \text{ in.}$$

Now, adding $\frac{1}{8}$ in. for wear and tear, we obtain thickness = 2.523 + .125 = 2.648 in. Ans.

1481. Fig. 433 shows the timber lining, brick walling, and tubbing employed in circular shafts, each, of course, being applied under different conditions.

L shows the timbers laid across the top of the shaft, *M* the timbering curve, *N* the punch blocks, *O P* the backing plank, *R* the stringing board, *S* the walling curb with the walling upon it, and *T* the hollow cast-iron wedging curb with cast-iron tubbing resting upon it.

1482. Water Rings.—Scarcely any strata which require walling will be perfectly dry, consequently water will percolate through the brick. It is caught in water rings, garlands, curb rings, ring curbs, or ring gibs that are put in, and from which the water is conducted to the sump through a line of pipes.

Figs. 434, 435, and 436 show the details of construction of several styles of water rings. In each figure, *a* is the crib, in which a gutter is usually hollowed out to catch the water, *b* is the walling both above and below the crib, and *c* is the waste pipe which conducts the water down the shaft from the gutter *d*.

1483. Brick, Stone, and Wood Walling.—When the shaft has been sunk deep enough for a walling staging, the seat for the segmental wedging curb is cut and the sinking carried down 5 or 6 feet, more or less as the case may require, below the curb, at the same diameter as the internal

diameter of the curb (see *a a*, Fig. 437). The walling at *A* is carried on simultaneously with the sinking at *C*.

When the walling *A* reaches the projection *a* above, the projection is gradually cut away and the walling *A* carried up and fitted closely to the previously constructed portion above.

The guides *c*, *c* are fastened at the surface, as stated in Art. **1473**; but here, instead of having weights attached to their lower ends, the building scaffold *s s* is attached, as shown in Fig. 437. The platform *s s* has a hole in the center, through which the bucket passes, and is permanently suspended in the shaft by the guide rods *c*, *c* at a height not exceeding 45 to 60 feet above the bottom.

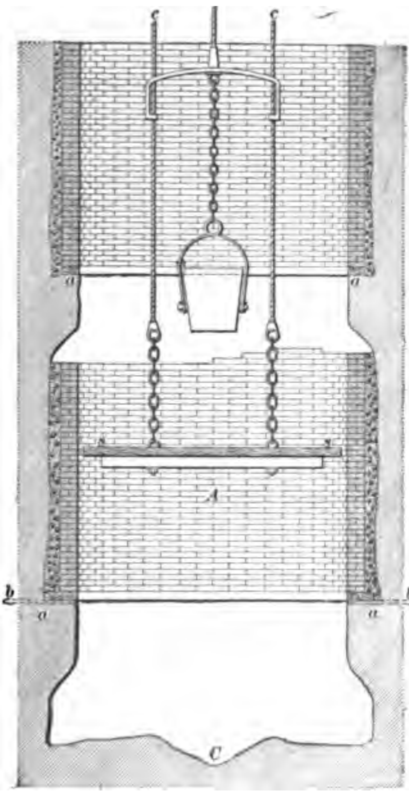


FIG. 437.

1484. The walling shown in Fig. 437 is either brick or stone, but in some cases wood is used. Fig. 438 represents such a case. The blocks are cut out of the best oak (all heart stock). They are about 3 feet long by 9 inches square. The joints are cut in radial lines, so that when the blocks are put in place they fit snugly and can not be pressed inwards.

The curb upon which this walling rests is likewise of wood. Between it and the ground is a space of about 6 inches in which there is placed a piece of wood *a*, about 2 inches thick, and between it and the ground the space

is filled with compressed moss *m*. Wedges *w* are then placed between this 2-inch strip of wood and the curb, and tightly driven in, thereby compressing the moss still more.

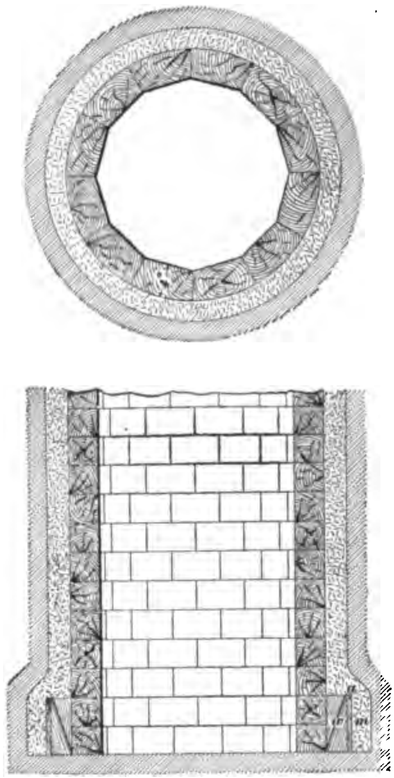


FIG. 438.

1485. Supporting Curbs.—Sometimes, in passing through broken strata, it is necessary to put in a supporting curb. There are several ways of doing this, but perhaps as good a way as any is to drill holes into the wall about 2 feet apart, taking great care to have them in a horizontal plane. Then the curb will be level when resting on bars of iron or steel, 2 or 3 inches in diameter, inserted in these holes. See *b*, Fig. 437.

1486. Bricks.—The dimensions of bricks for shaft lining vary, many engineers preferring under all conditions the ordinary rectangular brick. Some prefer the ends, and others the sides, curved to correspond with the inner and outer circumference of the shaft lining, while still others prefer to have the bricks molded into a form to suit the special case.

Good hard-burned rectangular brick, free from clinkers and pebbles, with a fairly rough face which ensures that they have not been over-burned, are the best.

Some engineers prefer to have all brick laid with the long side in line with the shaft diameter, while others prefer the

brick laid with the long side running with the circumference, every fourth or fifth course being laid contrariwise, as binders.

1487. There is no definite rule for determining the number of bricks required for shaft lining, on account of chipping and mortar, but an approximation may be made by the use of the following formula:

Let N = number of bricks required;
D = outer diameter of the shaft;
d = inner diameter of the shaft;
t = thickness of brick;
b = breadth of brick;
l = length of brick;
x = depth of shaft.

Then, $$N = \frac{(D^2 - d^2) \times .7854 \times x}{t \times b \times l}. \qquad (87.)$$

All dimensions must be in feet, or all in inches.

EXAMPLE.—If the outer diameter is 18 feet 6 inches, the inner diameter 18 feet, and the depth of the shaft 100 feet, and the size of the bricks is 8 inches by 3 inches by 4 inches, how many bricks will be required to line the shaft?

SOLUTION.—Substituting values, we have

$$N = \frac{(18.5^2 - 18^2) \times .7854 \times 100}{.25 \times .3333 \times .66666} = 25{,}800 \text{ bricks. Ans.}$$

As before stated, this is only an approximation, for as a general thing the number of bricks found by this formula will be from 10% to 15% more than will be required.

1488. Mortar.—In shaft lining, mortar should be used sparingly, and when water is to be resisted, good Portland cement should be used. In less important work, use equal parts of cement, lime, and ground ash clinkers (sand is too heavy) well mixed. To avoid getting mortar joints too thick, let the mason spread his mortar at a little distance from the spot where the brick is to set, then place the brick in it and slip it by gentle pressure into its proper place. The brick will carry sufficient mortar with it for its bedding.

1489. Substitute for Timbers.—Instead of putting in temporary timbers, as shown in section *c*, Fig. 433, the following method, which is better, is sometimes used: Four iron bands, 3 inches by 3¾ inches, of such length that combined they will be equal to the circumference of the shaft, with additional length for overlap so that they can be bolted together, are placed in position, and lagging is driven between them and the side of the excavation.

To prevent bulging of the wall, no cavities should be left between it and the strata. Some soft, compressible stuff, such as coke dust, should be used for filling, or if that can not be had, sand may be used.

1490. Uses of Curbs.—With any form of walling which must be water-tight, whether wood, stone, brick, or cast iron, a wedging curb is used.

Ordinary curbs are used where any form of walling not necessarily water-tight is used.

Supporting curbs are the same as the ordinary curbs, but are put in under different conditions, which have already been mentioned.

The "ordinary curbs" were formerly nearly always made of wood; but, as they are subject to decay, cast-iron curbs are beginning to supersede them.

1491. Plumbing the Shaft While Sinking.—In the rectangular and polygonal forms, a plumb line must be hung from each corner. In a circular shaft, a line may be hung in the center, and the sides of the shaft determined by a rod of the proper length reaching from the plumb line to the circumference. A better plan is to hang four plumb lines, one from each extremity of two diameters crossing each other at right angles. In an elliptical shaft, four plumb lines are hung, one at each extremity of both the major and minor axes. The plumb lines are fixed on a reel, so that the plumbs can be lowered as the sinking advances.

1492. Cement Tubbing.—Fig. 439 shows a method of lining shafts with cement, practised in some parts of Prussia.

This process has been found to offer great advantages in cases where the pressure is excessive. The cement blocks used are so shaped that they can be made perfectly water-

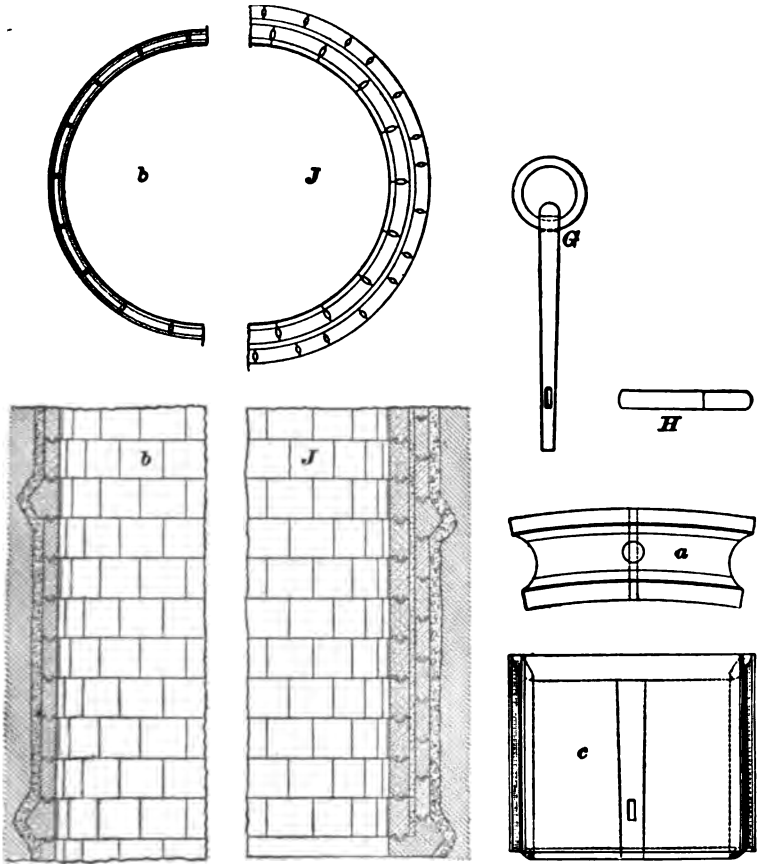


FIG. 439.

tight and will admit of easy setting. The shape of the blocks is apparent from the views *a* and *c*, Fig. 439. They are segmental, and are provided on the lower side with a semicircular groove, which corresponds with a semicircular ridge on the upper side, the groove being slightly deeper than the corresponding ridge, so that space is available for the reception of cement-mortar. On each side of the block

there is a channel for the reception of cement, the weight of the block being in this way reduced. In each block two holes are cored out, one of which is central and vertical, while the other passes radially from front to back, not in the middle of the block, but at some distance below that point, and intersects the vertical hole. The height of a block is 30 inches to 40 inches, and its weight from 1,500 to 1,700 pounds.

1493. In tubbing a shaft with cement blocks, the first layer of segments must be laid on the curb, on this the second layer, and so on, the vertical joints being broken in each course. In order to place a segment in position, a rod, provided with a ring or handle at the top, and with a slot near the lower end, is placed in the vertical hole. (See *G*, Fig. 439.) This rod is pushed down until the slot is opposite the horizontal hole, and then a bar *H* is pushed through, until it passes through the slot and holds the rod fast in the block. The winding rope may then be connected with the ring of the rod and the block lowered into position. Previously, however, the trough in the block below is filled with cement-mortar. When lowered, the ridge of the block coming in contact with the mortar forces it into every crack, and a water-tight connection is effected between the horizontal layers of blocks. The vertical hole is then filled with a lump of clay which is rammed in, and a bar is pushed through the horizontal hole, which has become choked at the point of intersection, and the hole is reopened. The bar is allowed to stay until the clay has hardened. On withdrawing it, a channel is formed, through which the water collecting behind the tubbing can flow. Between every two blocks a tubular joint is formed, which is filled with cement-mortar or concrete rammed in as tightly as possible. The horizontal holes, which had hitherto served as drainage channels, are closed by cork, wood, or clay; and if, at a certain height in the shaft, there is a supply of good water, it can, without difficulty, be piped away.

When the segments are formed into a complete ring, the perpendicular grooves are filled in with a special mixture of

cement, and concrete is rammed into the space between the segments and the sides of the shaft. Above each cement block a thin layer of cement is spread, and on this the segments of the ring above are placed. (See *b*, *b*, Fig. 439.)

In some cases a double ring of cement segments is employed (*J*, *J*, Fig. 439). Here a course of cement blocks for the back wall is first laid, and cement rammed in behind. This course is about half a block higher than the inner layer, so as to break the horizontal joints. The courses of the inner ring are then laid in such a way that the vertical joints do not coincide with those of the back ring. The joints are carefully filled with cement, and the intermediate space of about 4 inches between the inner and outer rings is then filled in with concrete tightly rammed. In this manner a thoroughly water-tight tubbing is obtained.

1494. In shaft sinking, cement is found to be a valuable auxiliary, particularly in the special setting of masonry known as coffering. Cement, too, has been employed in an ingenious way for consolidating shifting sand in water-bearing strata. The method employed consists in injecting powdered cement, by means of compressed air, steam, or water under pressure, into the ground to be consolidated. The cement is screened in order to free it from lumps, and the powder is taken by an injector which forces it through a flexible pipe into a perforated tube sunk in the soil to the required depth. In this manner the soil becomes impregnated with the powdered cement, while the water is driven away from it.

THE PROCESS OF SINKING.

DRILLING.

1495. When, in shaft sinking, ground is reached that is too hard to be excavated by the sinking pick (which is simply a heavy pick made like the ordinary mining pick) and wedges, explosives are used. The operation of blasting consists in boring holes of suitable diameter and length in favorable positions in the pit bottom, in inserting the charge of

the explosive compound in the lower portion of the hole, in filling up and ramming with suitable material the remaining portion of the hole, and in exploding the charge. These holes are made either by "churn drills," "jumpers," or power drills.

1496. The **churn drill** is a bar of round iron, swelled in the center to give weight, having a bit on each end. This is raised and forced down by the hands of one or two men in the same manner as a percussion boring machine makes its stroke. It is turned slightly at each stroke to keep the hole round.

In the shaft bottom the conditions are frequently such that the holes must be drilled at different angles. So long as the boring is vertically downward, or the angle from the vertical is slight, the churn drill is very effective. But in sinking operations, holes must be drilled at all angles, and it is obvious that in some of these directions the churn drill is practically worthless. To meet these conditions, the ham-

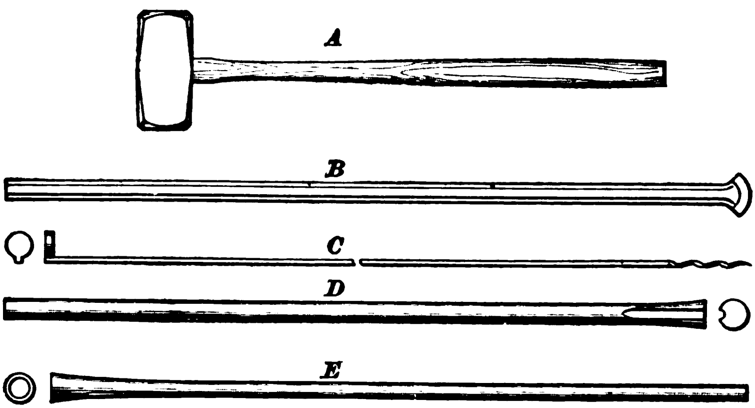


FIG. 440.

mer and jumper shown in Fig. 440 are used. This figure shows a set of double hand rock tools.

A, sledge hammer, weight 5 pounds or more.

B, drill, of which there are usually three in a set, the dimensions being 18 inches long, with $1\frac{1}{16}$ inches cutting

edge; 27 inches long, with $1\frac{3}{4}$ inches cutting edge; 40 inches long, with $1\frac{5}{8}$ inches cutting edge.

C, scraper and drag-twist.

D, rammer, or copper-headed tamping bar.

E, bêche.

1497. The method of using these tools is as follows: The hole having been started, the short drill is inserted and held in position by one man, while the other, called the "striker," strikes the top of the drill with the sledge hammer. The man holding the drill gives it a slight turn after every blow so as to ensure a round hole. After the short drill has gone in about half way the second drill takes its place, and after that the long drill. The scraper is a thin iron rod with a round, flat end, turned up at right angles to the stem, for the purpose of scooping all the sludge and débris from the hole. The drag-twist at the other end of the scraper is a spiral hook. To ensure the hole being thoroughly clean and dry, a wisp of hay is pushed into the hole and the drag-twist is then inserted until it becomes entangled in the hay, which can then be removed.

When the hole has been cleaned, the charge of explosive is inserted and the fuse laid to it. The hole now needs tamping, and this is done by plugging it up by means of the tamping bar *D*. It will be observed that there is a groove cut out along one side of this tool, the object of which is to allow for the space occupied by the fuse along one side of the hole, when the clay is being tamped or rammed. The bêche *E* is simply a rod with a tapered hollow end for the purpose of extracting a broken drill, if necessary.

1498. In extra hard rock the diamond drill, shown in Fig. 441, and the rock drill, a type of which is shown in Fig. 442, have been used to advantage. These may be operated by steam or compressed air; the latter is most commendable for the comfort of the sinkers, but from a point of economy steam may take precedence.

The drill shown in Fig. 441 may be operated by hand, if it is so desired. If the number of revolutions is great, the diamonds in the bit pass very rapidly over the surface, wearing it lower and lower, and thus the bore hole is carried down, the machine stopping only when the core barrel is filled with the core of the strata, or when another length of rod must be attached. The hole may be drilled any depth, the blasting being regulated by filling the hole with sand, which is removed as further depth is required.

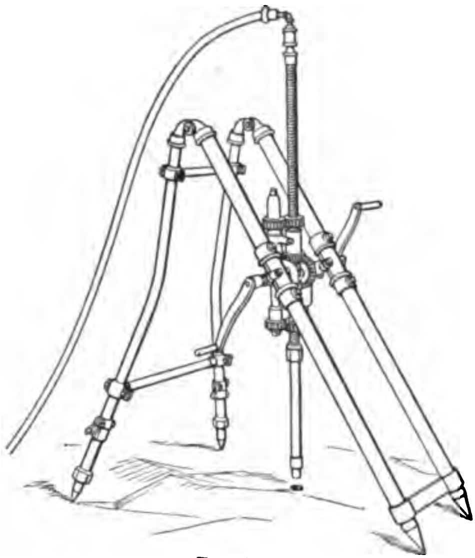


FIG. 441.

1499. Fig. 442 is a percussion drill which may make as many as 500 double strokes per minute. The mechanism slightly turns the drill at each blow, which results in a circular hole of a diameter a little larger than that of the cutting tool. As the drill works, the sinker turns the handle of the advancing screw A, and so causes the cylinder to move down the slide B, thus keeping the point of the drill up to its

FIG. 442.

work. This slide being say 18 inches long, the hole can be drilled that depth. When this depth is reached the screw is reversed, the drill drawn out of the hole, and a longer drill placed in the hole and fastened to the piston. The second drill is rather narrower than the first, so that it will not catch on the sides of the hole. When the entire length of this drill has been bored, if it is still necessary to go deeper, a third and then a fourth drill can be added.

Percussion drills may be used to put in any number of holes desired, and at any angle. The number of holes and their position will depend upon the form and size of the shaft. The holes generally vary in depth from 3 feet to 4 feet, and in diameter from 1¼ inches to 2 inches.

Sumping holes are the first holes drilled and fired in a level pit bottom. They should be placed near the center, and inclined at an angle of from 20 degrees to 40 degrees, and should not be too deep, say 3 feet in hard rock.

BLASTING BY FUSE.

1500. In blasting by fuse, frequently four or more holes are lighted at the same time, lengths of fuse being used, so that the shots go off one after the other, allowing each detonation to be counted, so that the sinkers may know if all have fired. Fuse blasting is objectionable, because, under many conditions of sinking, the simultaneous discharge of blasts gives the best results. As each shot mutually assists the other, the result is about 1.4 times as powerful as that obtained from consecutive firing. Fuse firing is dangerous, because the fuse may hang fire.

Time fuses are in use at present, but they can not be relied upon under all circumstances, and especially when subjected to the varying conditions of damp holes. Time fuses are made of cotton or hemp, either single tape or double tape. Some are made of gutta percha, and others of an outer and inner casing of special material, according to the conditions under which they are to be used. The best is inferior to the electric exploder.

1501. In firing ordinary powder with a fuse, the fuse is first cut to obtain a fresh surface. One end is doubled back and fastened by a string loop. It is then inserted in the cartridge, as shown in Fig. 443, and the mouth of the cartridge carefully drawn together and tied. It is now ready to be lowered into the hole. By using a gutta percha fuse and water-proof paper, wet holes are frequently fired with black powder.

FIG. 443.

1502. With nitroglycerin explosives, a percussion, or detonating, cap is placed on the end of the fuse and inserted in the cartridge. Safety in the use of high explosives requires extreme care. Sharp pieces of metal—a knife blade, for example—should not be brought in contact with the cartridge. The fuse is inserted in the detonator, and the end of the latter is "crimped" so as to firmly hold the fuse, as shown in Fig. 444. It is bad practice to attempt

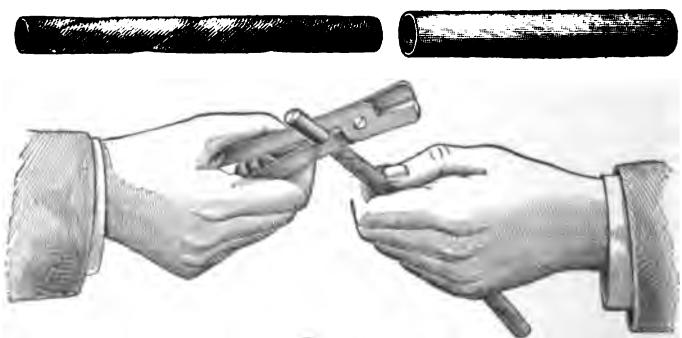


FIG. 444.

to secure the cap to the fuse in any other way, as the detonator is liable to explode and cause a serious accident. Having secured the cap to the end of the fuse, open the end of the cartridge, and, with a sharpened piece of wood, punch a hole in the end of the cartridge large enough to receive the cap, but do not insert the cap so far that there will be any danger of the burning fuse starting a deflagration of the cartridge before it is detonated.

The cap should be inserted only ¾ of its length to avoid such an occurrence. After inserting the cap, close the end of the cartridge, and tie securely with a string, as shown in Fig. 445. The cartridge so prepared is called the **primer.**

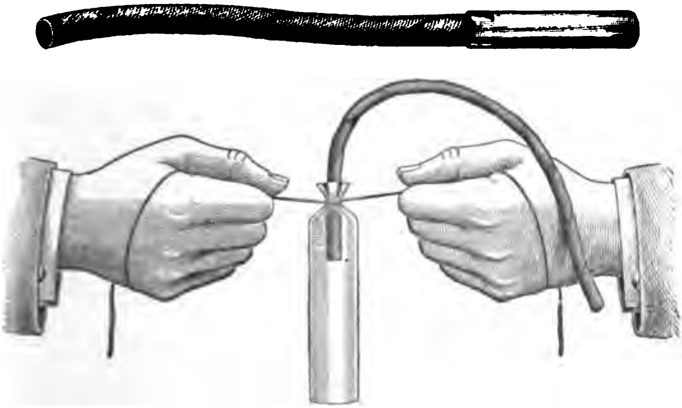


FIG. 445.

When a number of cartridges are inserted in the same hole, the detonation of the *primer* is sufficient to explode the entire charge. The size of the cartridge should be such as to fit fairly snugly in the hole. The cartridges must be inserted and pressed home carefully, one by one, the primer being inserted last and pressed tightly down upon the charge, and then the "*tamping*," or "*stemming*," should be inserted.

1503. Holes are charged by putting in one or more cartridges, and squeezing each with a wooden rammer. The best tamping for a drill hole is that which will not blow out; it must be of a strong resisting character—something which changes form when disturbed, and which tends to wedge. The best tamping, except small stones, is sand, and the worst is wet clay. If substances which are near at hand will serve the purpose, they had better be used.

The power of the explosion is improved by good tamping, because it confines the forces generated by the blast within the hole. In order that even nitroglycerin explosives may be well tamped, a soft substance, such as clay, is put directly

on top of the cartridge, and gently pressed home; on top of this, the tamping may be rammed tighter and tighter as it comes nearer the top of the hole.

ELECTRIC BLASTING.

1504. The American method of electric blasting depends upon the generation of a current of electricity in a similar manner to the production of electricity for lighting purposes, the current producing incandescence in a wire which is submerged in an explosive. A magneto-electric machine is simply a small dynamo operated by hand, the electric current being produced by the rapid revolution of an armature, or a coil of wire, between the poles of a magnet. The current is generated in the machine, and when it is at its greatest intensity, it is discharged into the circuit which contains the exploder. In this way the electric current passes over a fine platinum wire bridge, which offers so much resistance that the wire becomes red hot, and this heat explodes a small quantity of fulminate of mercury which is in the cap.

1505. Fig. 446 shows a cap with wire connections. The wires *C*, leading from the battery, are connected by a fine platinum bridge *E D*. *F* is a cement, usually made of sulphur, for the purpose of holding the ends of the wires intact,

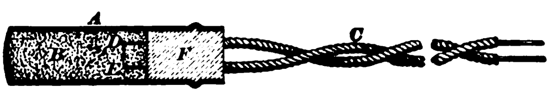


FIG. 446.

and serving to seal the mouth of the exploder. *B* is the fulminating mercury. The whole is encased in a tube *A*, which is similar in appearance to a gun cartridge. It is about 1¼ inches long and ¼ inch in diameter. The wire *C* should be of pure copper, of about No. 20, American wire gauge, and well insulated by cotton or other substance, wound double over the wire.

The passage of electricity through any substance is practically instantaneous when compared with the passage of

heat. Therefore, in a hole where there are several cartridges, to ensure immediate explosion of all of them, an exploder should be placed in every second or third cartridge; the best result will be secured if there is an exploder in each.

When blasting is done under water (the result accomplished is then only $\frac{1}{4}$ that of dry blasting), and whenever the explosive is gelatin, gun-cotton, forcite, or dynamite, the double strength exploder should be used.

1506. The greatest explosion that can be made is produced when the detonation is sufficient to ensure the immediate explosion of the entire charge. If dynamite which has frozen is not thawed out, it will take a much higher initial explosion of detonation to set it off. In some cases, several ounces of powder are put in the hole in contact with the exploder and on top of the dynamite, in order to produce the large amount of shock and heat to discharge the higher explosive—dynamite.

1507. The explosion is simply the conversion of the solid into a gas. The gas occupies more space than the solid; hence, in the tendency to expand it breaks the rock. The higher the grade of the explosive the more sudden is the conversion into gas, and the more effective is the blow which it delivers in the drill hole. This suddenness of conversion into gas is sometimes of more importance than the number of volumes of gas produced by a certain number of cubic inches of the explosive, as it increases the amount of work done.

1508. For firing by electricity, two systems of connecting the wires to the machines are in use. In the first, Fig. 447, the fuses are connected in **series**; that is to say, one wire of the first hole is connected to one wire of the second hole, and the other wire of the second hole to one wire of the third hole, and so on, until all are joined, when there will be one wire of the last hole and one wire of the first hole left unconnected. These are now joined by wires to the machine, which is in a place of safety.

In the second, Fig. 448, the fuses are connected in

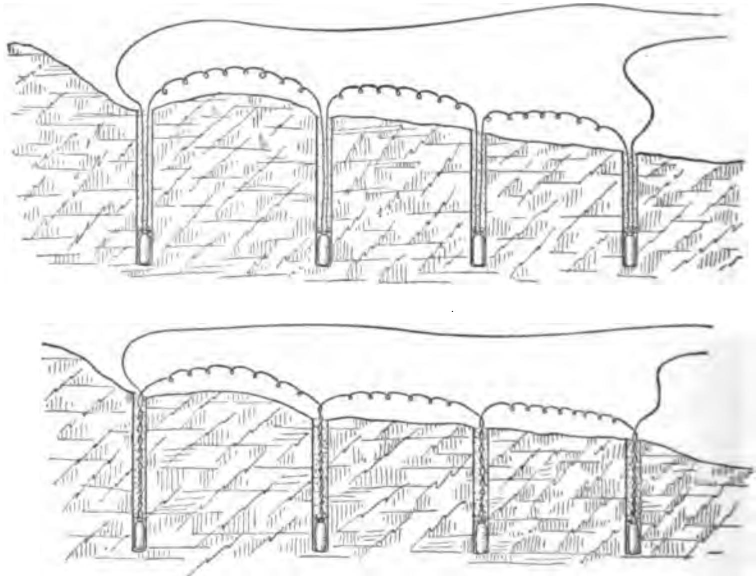


FIG. 447.

parallel. In this case the positive wire of each detonator is connected directly to the positive wires from the machine,

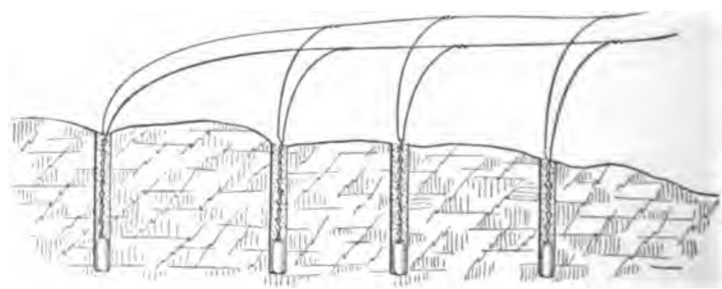


FIG. 448.

and the negative wire is connected to the negative wire from the machine.

Modifications of the "series" and "parallel" systems are possible, as the holes may be connected in multiple series, as shown in Fig. 449.

1509. The connecting wire, sometimes called the fuse, varies with the length of the hole.

The making of the joints which connect the wire from the

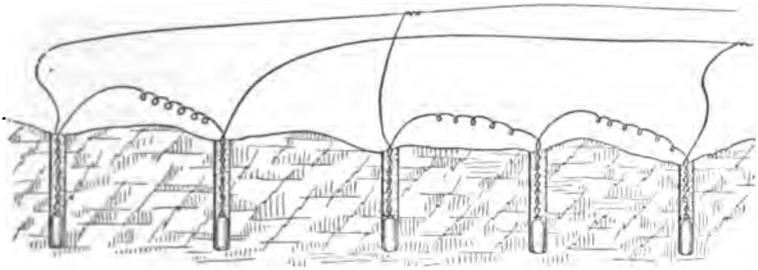


FIG. 449.

battery with the fuse is not so simple an operation as would appear. The first thing to do is to bare the wires; if they are already bare, it is best to use a knife to scrape them, thus removing all oil or other material which may interfere with a perfect connection. Two points must be observed. One is to bring the two wires in thorough contact with each other, and the other is to so connect them that they will not pull apart. In order to do this, both wires should be twisted in the manner shown in Fig. 450.

The two ends should be brought together with both hands, and, by means of each thumb, twisted alternately, one wire

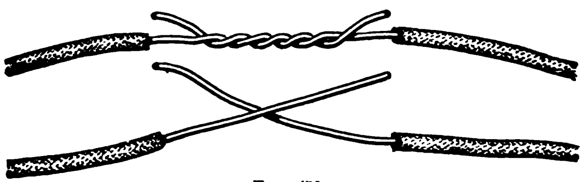


FIG. 450.

around the other. In this way they are not only brought into perfect contact, but they are tied together.

Connecting wire is usually made of copper, because of its high conductive power.

With machine drills and electric, or simultaneous, blasting, there is not so much necessity to consider the line of least resistance, but it should be taken advantage of as often as possible.

F. II.—12

1510. Electric Blasting Apparatus.—Fig. 451 shows a good type of magneto-electric machine, weighing about 16 pounds and occupying less than ½ a cubic foot of space. These machines are of different capacities; one kind will fire 15 holes, while another kind will fire from 25 to 40 holes. With these machines no uncertainty exists.

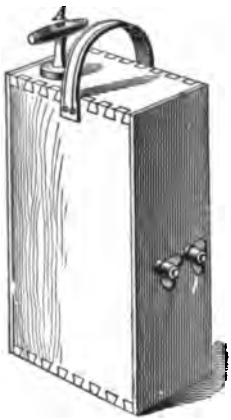


FIG. 451.

In using these machines a fuse, or exploder with two wires attached, is used as already described. The charges having been connected as directed (the leading wires being long enough to reach a point at a safe distance from the blast) and all being ready, the workmen connect the leading wires, one to each of the winged nuts on the front side of the machine. This is accomplished by placing the wire between the nut and the shoulder and tightly screwing the nut against the wire.

To fire, take hold of the handle *A* and lift the rack (or square rod, toothed upon one side) to its full length, and press it down, for the first inch of its stroke with moderate speed, but finishing the stroke with all force, bringing the rack to the bottom of the box with a solid thud, when the explosion will take place.

EXPLOSIVES.

1511. M. Berthelot describes nitroglycerin as "really the ideal of portable force. It burns completely without residue—in fact, gives an excess of oxygen; it develops twice as much heat as powder, three and a half times more gas, and has seven times the explosive force, weight for weight, and taken volume for volume, it possesses twelve times as much energy."

1512. The name "high explosives" is generally applied to that class of explosives of which nitroglycerin is the active principle. They are commonly known by the

name of **dynamite.** This usually burns freely without explosion when unconfined in the open air, but when fired by a blasting cap it explodes with enormous force.

All nitroglycerin compounds freeze at 40° F., and resume their soft, pasty condition upon being warmed. To secure its full explosive power, dynamite must never be used in even a semi-frozen state. All nitroglycerin compounds decompose when exposed to the direct rays of the sun for any length of time, whatever the temperature of the air may be, and hence lose their efficiency. All frozen cartridges should be thawed; as, when frozen, the powder loses much of its efficiency, its properties change and it is difficult to explode it with a cap.

1513. When the cartridges are frozen, they should not be exposed to a direct heat, but should be thawed by one of the following methods:

1. The number of cartridges needed for a day's work should be placed on shelves in a room heated by steam pipes or a stove. If a small house is built for this purpose, it should be banked with earth, or preferably fresh manure.

2. The cartridges may be put in a water-tight kettle and this placed within a larger kettle, filling the space between the kettles with water at 130° F. to 140° F., or at such a heat as can be borne by the hand. If the water cools, it should not be reheated in the kettle, but fresh warm water should be added. The kettles should be covered to retain the heat. The temperature should not be allowed to get above 212° F.

3. When the number of cartridges to be thawed is small, they are sometimes placed about the person of the workman until he is ready to use them, but this is a dangerous practice.

Cartridges should not be thawed by putting them in hot water or by exposing them to live steam, as this (unfortunately very common) method has an injurious effect on the powder. Neither should they be thawed by holding them in the hand before a fire. Cartridges exposed after

thawing freeze again rapidly. They may be carried to where they are to be used in sawdust in a box, so as to prevent their freezing.

1514. The following table, by Berthelot, gives a valuable statement of the heat, volume of gas, and the explosive force (relatively) of prominent explosives:

TABLE 30.

Substance.	Heat.	Volume of Gas.	Estimated Explosive Force.
Blasting powder	510	0.173 liter	88
Artillery powder	608	0.225 liter	137
Sporting powder	641	0.216 liter	139
Powder, nitrate of soda for its base	764	0.248 liter	190
Powder, chlorate of potash for its base	972	0.318 liter	309
Gun-cotton	590	0.801 liter	472
Picric acid	687	0.780 liter	536
Picrate of potash	578	0.585 liter	337
Gun-cotton, mixed with chlorate of potash	1,420	0.484 liter	680
Picric acid, mixed with chlorate of potash	1,424	0.408 liter	582
Picrate, mixed with chlorate of potash	1,420	0.337 liter	478
Nitroglycerin	1,320	0.710 liter	939

NOTE.—A *liter* is equal to 61.027 cubic inches.

SPECIAL SINKING DEVICES.

1515. In Europe many special devices are used for sinking shafts under difficulties, as through quicksand, heavy feeders of water, etc. It does not seem probable that all of these methods will be entirely successful in this country. They may be modified to meet the peculiar con-

ditions of each case; but these modifications must, in some respects, be radical, and the best results will be obtained by adopting from each of the several systems the methods and appliances that are best suited to the case.

In order to pass through quicksand, special means are employed, the principal ones being (1) the Piling method, (2) the Drum method, (3) the Gobert or improved Poetsch sinking process, and (4) the Triger method.

PILING METHOD.

1516. When the quicksand or other soft material is near the surface, the method of piling shown in Fig. 452 is employed. This requires the shaft at the commencement of the soft material to be very large, especially where it must be carried to a considerable depth.

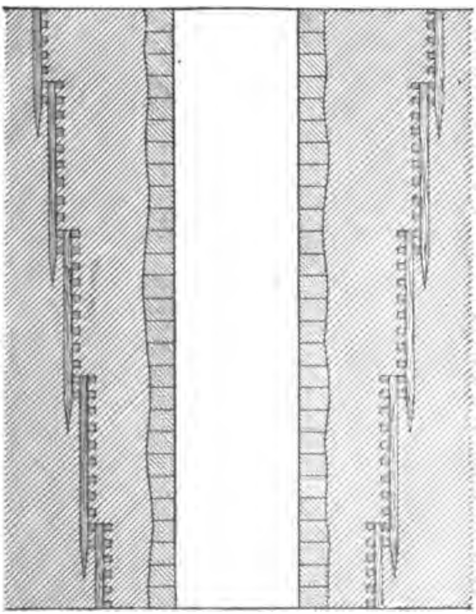


FIG. 452.

In such a case, a wooden curb of the size and shape of the opening is laid down in its true position. This may be made of oak about 9 inches wide and 6 inches thick. Outside of this, and all around it, piles from 6 inches to 9 inches wide and 3 inches thick are driven as deep as possible without breaking. After the first set of piles have been driven at the surface, excavation is started. When the excavation reaches a depth of about $\frac{3}{4}$ the length of the piles, the work is squared up, and the second set of piles is driven within

the first set as shown. This operation is continued until the quicksand is passed.

Assuming that the piles are shod with iron and are capable of being driven 15 feet deep, and that the curbs used in lining the shaft are 9 inches wide and the piles 3 inches wide, each course of piling will reduce the size of the opening $(9'' + 9'' + 3'' + 3'') = 24$ inches $= 2$ feet. With a pile 15 feet long a course will be required every 12 feet. The reduction of length or width in a thickness of 96 feet will be $\frac{96}{12} \times 2 = 16$ feet; if the size of the shaft had to be 10 feet by 24 feet, to allow of a net size inside the timbers of 8 feet by 22 feet, it would have to be $10 + 16 = 26$ feet, and $24 + 16 = 40$ feet, giving 26 feet by 40 feet as the size at the top of the quicksand.

If we desired a shaft $17\frac{1}{2}$ feet in diameter, then $17\frac{1}{2} + 16 = 33\frac{1}{2}$ feet would be the diameter at the top of the quicksand.

1517. In order to keep the shaft the same width throughout, and that piling may be used when quicksand or other loose material is met at some depth from the surface, the style of piling shown in Fig. 453 is used. This system is applicable where the sand bed is very thick. The piles are driven at an angle of 40 degrees, or thereabouts, from the vertical on each side of the frame. The shaft is then deepened 2 or 3 feet below the first curb, or frame, and then another set of slanting piles is driven as before, and so on till solid ground is reached. When the quicksand is very free, intermediate curbing sets may be necessary in addition to the piles.

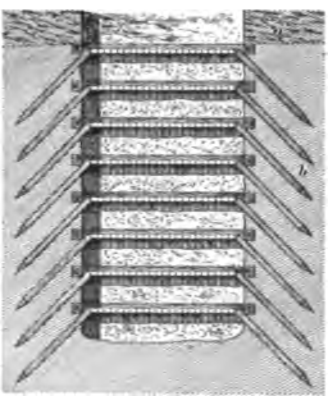


FIG. 453.

When the piling has reached the bed-rock, a wedging

curb is laid and the walling is run up through the treacherous ground as expeditiously as possible. Where water is encountered under considerable pressure, the piling method is not suitable, as the sand will flow in as rapidly as it is excavated. To overcome this a great many methods have been devised; the most important one will be explained later.

1518. In cases where the quicksand is raised by the water pressure and boils upward into the excavation, work may be facilitated to such an extent that but little, if any, piling is required, a series of wells being driven, each of which is an ordinary driven-well tube having a suitable perforating point and strainer at its lower end. The wells are connected at their upper ends, by means of pipes and couplings, to a suitable pump, receiving the water through a sand box. In practice, the wells are driven about 8 feet apart, and about 8 or 10 wells are connected to a pump. In some cases, after pumping a few hours, the boiling springs of quicksand entirely cease, and the removal of the water so quiets and solidifies the quicksand that it can be freely handled with a shovel.

DRUM METHOD.

1519. Pile driving is most expensive, and is in many cases superseded by the so-called Drum method. In this system, a drum, either of wood or iron, of a size sufficiently large to allow the permanent walling to be inserted inside it, is sunk in the sand. The drum may be circular or rectangular, as desired.

1520. Wooden Drum.—A curb 12 inches to 18 inches wide and 6 inches deep is first laid down perfectly level on top of the bed to be sunk through, and a tier of masonry built upon it to a height of about 3 feet. (See Fig. 454.) A second curb is laid and connected to the first by iron tie-bolts, which are inserted before the masonry is built, so that the masonry may not be broken or deranged in any way. A water-tight lining of plank is placed behind it and

nailed to the curbs. When the ground is loose, the drum will sink into it by its own weight, but in beds more or less coherent, cutters, or iron shoes, are attached to the bottom as in the iron drum to be described later.

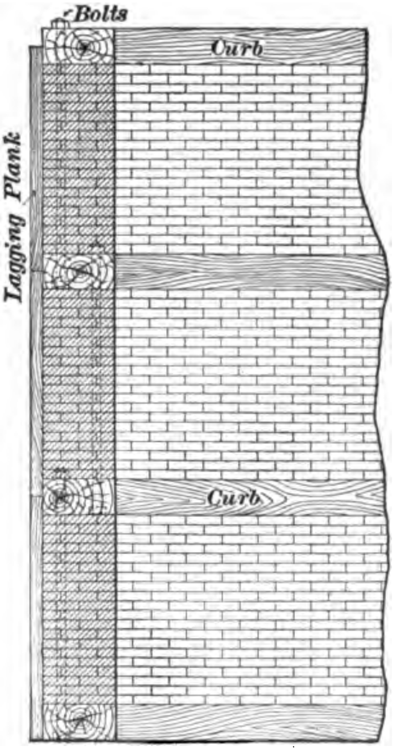


FIG. 454.

In some cases, when exceptionally hard substances are met, it is not advisable to use cutters, because the tendency is to turn the cutter outward, which may rupture the drum. The drum should be kept perfectly level, the ground which offers the most resistance to its downward movement being removed.

At every 3 feet of advance a new curb is put on top of the last one and bolted as before, and so on to the end.

The greatest difficulty in this method is the tendency to "cant" to one side. The drum can not be relied upon to go down regularly. It will at times go rapidly, and at other times scarcely move, and if the material is a little softer on one side than on the other, it is inclined to cant that way. This is overcome by removing the ground from the harder side, or adding more weight to the drum on that side, or by doing both together.

The objection to wooden drums is that they require nearly as large an excavation as the piling method; for, in many cases, the whole structure sticks and can not be moved,

and the only remedy is to sink a second one, telescope fashion, inside the first.

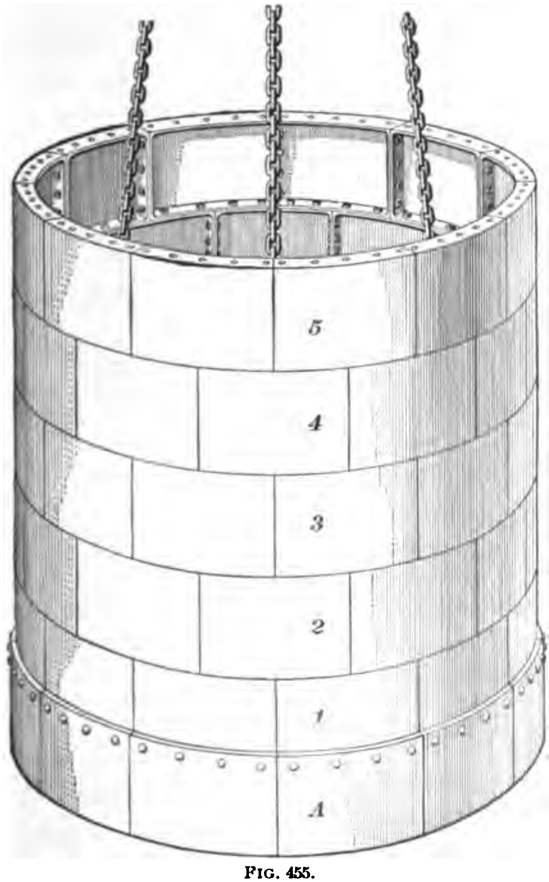


FIG. 455.

1521. Iron Drums.—These may be circular or rectangular, of cast iron or wrought iron. Although they sometimes have to be telescoped one within the other, the consumption of space is not nearly so great as with wooden drums. In the case of a circular drum, Fig. 455, the segments vary according to the diameter, ranging from 4 feet to 5 feet in length, and 2 feet in depth. They are strengthened by vertical and horizontal ribs on the inside. The

outside is perfectly smooth, and meets with little resistance in passing through the ground. The joints between the segments are filled with sheet lead, the segments being drawn together by bolts. The ribs are made broader where weights have to be used to sink the drum, and the cutter (Fig. 456) is attached to the bottom segment.

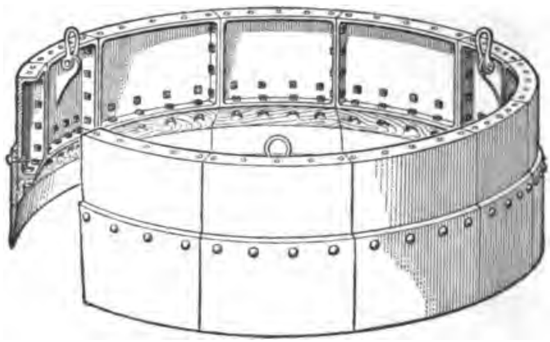


FIG. 456.

Sometimes the drum will sink too fast, and unevenly. To avoid this, the tubbing is hung at three, four, or more points by chains and a lowering screw arrangement from transverse beams at the surface. The speed can in this manner be regulated at will, and when boulders, or any other obstructions, are met, they can be removed to prevent canting the drum.

1522. Cast-iron drums are not suitable for unequal strains, so in work where such strains are expected wrought-iron drums should be used.

Fig. 455 shows a drum with five tiers of segments above the cutter *A*, and Fig. 456 shows a perspective view of the cutter.

THE IMPROVED POETSCH, OR GOBERT FREEZING PROCESS.

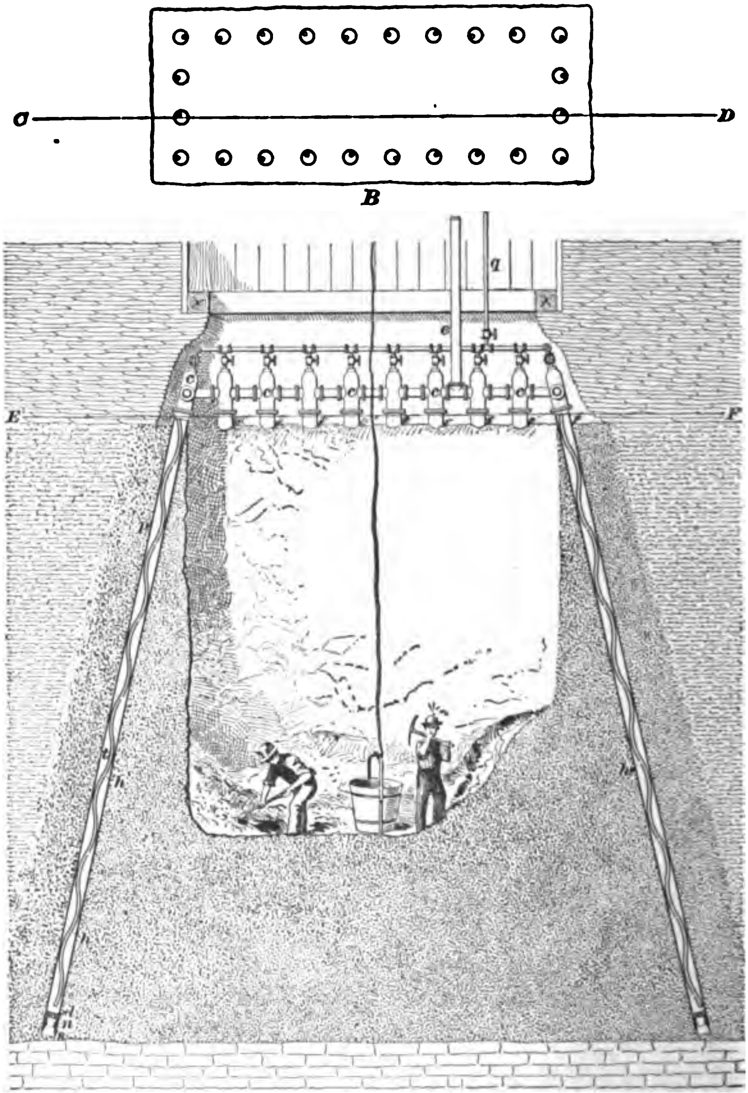
1523. When beds of quicksand are met at considerable depths below the surface, the foregoing methods are impracticable, and are replaced by an ingenious method known as Gobert's freezing process. In this system, tubes are forced through the water-bearing strata, and such a degree

of coldness is produced within the tubes that a cylinder of ice is formed around them. By placing the tubes in the proper position, an ice wall or dam may be formed around the line of shaft, or if sufficient time be given for the freezing, a solid mass of ice will form directly below the shaft, enabling the workmen to continue the sinking with unusual rapidity and a fair degree of safety.

1524. In Fig. 457 are shown a vertical and horizontal section of a shaft where this system is applied to a bed of quicksand about 30 feet thick and producing such a quantity of water that the pumps can readily keep it to the level of the bed. The vertical section *A* is taken on the line *D* and the horizontal section *B* on the line *E F*. Large wrought-iron tubes *p*, about 8 inches in diameter, are driven into the quicksand at such an angle that the permanent walling can be put in without removing them. These tubes are connected together at the top by cast-iron fittings *c*, and provided at the bottom with a circular shoe *s* to facilitate the passage of the tubes through the quicksand. They are also closed at the bottom, after being driven to their permanent position, by a lead plug *n* and several alternate layers of cement and pitch *l*. Within each tube *p* is placed a small tube *t*, having a helicoidal or serpentine shape, and provided at the top with a valve *v* to regulate the inflow of the liquid which produces the lowering in temperature. The tubes *t* are also connected together above the valves *v*.

1525. When the system is properly connected, anhydrous liquid ammonia is forced from the refrigerating plant at the surface down the tube *q* into the small serpentine tubes *t*, along which it is allowed to escape into the tubes *p* through small orifices *h* placed in the valley-beds of these tubes. The liquid continuously flows in thin streams through the orifices, vaporizes, and, consequently, takes up a great deal of heat from the surrounding strata, causing them to freeze. This vapor is forced through the tube *c* to the refrigerator, where it is deprived of its heat and again compressed into a liquid ready to return through the tube *q*.

The pressure within the tubes p is almost invariably less



A
FIG. 457.

than the external pressure, thereby preventing any possibility of the liquid flowing out in case of a break in any of

the tubes. Should any of the liquid escape, an uncongealable mass would be formed around the tube, resulting in serious difficulties. It is best to have the small tubes *t* touch the sides of the tubes *p*, so that the heat will be readily conducted from the strata to the liquid.

1526. When beds of quicksand which produce enormous quantities of water under great pressure are met, the shaft is allowed to fill up and long tubes are put down through the quicksand from the surface along the sides of the shaft. In such a case no pumping is required while the freezing goes on at the bottom of the shaft. This result of freezing the strata at the bottom of the shaft only is accomplished by simply providing the tubes *t* with orifices near the bottom, or for a distance along the lower ends of the tubes equal to the thickness of the strata to be frozen.

1527. It is often advantageous to have the freezing begin at the top of a thick bed of quicksand and proceed downwards. This can be accomplished by a small supply of the liquid, which will completely vaporize before it reaches the lower ends of the tubes *t*. When this is done, the top freezes and, therefore, will not give up heat readily; this causes the liquid to go down further to become vaporized, thus carrying the freezing gradually to the bottom of the tubes. When the tubes are put down from the top of the shaft, they are made up in sections joined together by means of an internal jacket so as to keep the outer surface of the tubes uniform, and each tube is closed before being put down. While sinking, the verticality of the tubes can be tested either by the thermometer or by driving short horizontal headways from the shaft into the pipes. The system is applicable to both rectangular and circular shafts.

TRIGER'S METHOD OF SINKING.

1528. Triger's method of sinking through running and wet surface ground and the construction and mode of action of the Triger tube are very interesting. By reference to Fig. 458, it will be seen that what is called the tube is built up of three short cylinders, joined by their inside horizontal flanges,

the joints being made air-tight and free from outside obstructions. The weights L force the tube into the water-bearing strata.

The tube is divided into three chambers by two decks,

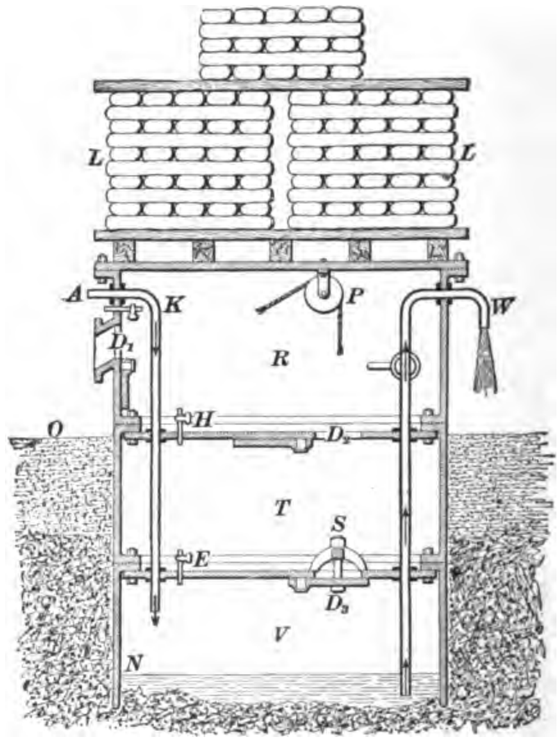


Fig. 458.

and entrances into the middle and bottom chambers are provided through the doors or valves D_2 and D_3. The pressure of the compressed air always exceeds the pressure due to the water head. Let O be the surface water level, and N the water level within the tube. If $O\,N = 50$ feet, it will require a pressure due to a water head of 70 feet to keep the ground within the tube practically free from water. In the figure, the valves D_1 and D_2 are open, and the valve D_3 is closed.

The compressed air enters the chamber V by the pipe A. The water within the tube is then pressed out through the pipe W. The mode of entering and leaving the chambers is interesting, and is as follows: It seldom (or never) happens that the valves D_2 and D_1 are open together when D_3 is closed, it being so arranged in the figure only to make the details plain.

Suppose it is necessary for gravel and stones to be lifted from V into T, or for the workman in V to pass up into T. The valve D_2 is then closed by a workman in the middle chamber, who also opens the small tap E, and in a short time the pressure in T is equal to the pressure in V. The workman in V then opens the valve D_3, when he can pass into the middle chamber T; or stones and dirt can pass from V into T. If a change of workmen is to take place, one passes into V, and closes D_3; the man in the middle chamber is then relieved by the tap H being opened; D_2 is then opened, and the two men change again. The man passing into T shuts D_2, and opens E to equalize the pressure between T and V, and the man in R opens K to equalize the pressure with that of the atmosphere, when he can open D_1 either to discharge dirt or pass out himself. The pulley P is used in raising or lowering men or material through the valves D_2 and D_3.

After a bed of rock is reached by this process, the inside of the cylinder is lined with brick to prevent damage to flanges which might occur in working the shaft for mining purposes.

1529. The depth which can be reached by this method is limited; for the pressure of water outside the cylinder increases with the depth, and a higher pressure of air must be used in the lower compartment to stop the inflow of water. A point is soon reached at which sinkers can not work. As much as 121 feet of quicksand have been passed through by this method, the greatest atmospheric pressure being about 41 pounds per square inch.

There are other pneumatic systems, but they are all subject

to the drawback that men can not work when the pressure exceeds 45 pounds per square inch above the ordinary pressure, and even at less pressure great care is necessary to avoid ill effects on the sinkers.

SINKING THROUGH HEAVY FEEDERS OF WATER.

1530. The principal methods of sinking through heavy feeders of water are the Kind-Chaudron and the Lippman.

1531. The Kind-Chaudron System.—This is applicable only to circular shafts, and is undoubtedly the best where heavy feeders of water must be contended with.

Four or five men stand on a working floor 16 feet below the surface, to which depth the diameter is from three to four feet more than the size of the shaft below. From this point, the shaft is carried down by the ordinary method to the water level, and walled up with brick or wood. The shaft stands full of water and unlined until the boring has reached solid rock below the water-bearing strata, when the tubbing is put in place.

1532. The excavation is effected in two successive stages. At first, a cylindrical hole of about 4 feet 6 inches or 5 feet in diameter is bored, which is usually kept at least 35 feet further advanced than the full size shaft. This hole is enlarged to the full size of the shaft by the second or third operation.

The manner of cutting the excavation is the same in the first and second stages; the removal of the débris in each stage is accomplished differently.

In each case, the cutting tool *T*, *T*, Fig. 459, called a **trepan,** consists essentially of a horizontal bar of wrought iron, to the under surface of which are attached steel teeth, so placed that as the bar is rotated around the central axis of the shaft, each tooth, in falling with the bar through the requisite length of the stroke, generally 10 inches to 20 inches, cuts for itself an annular portion of the bottom of the shaft. The trepans, both large and small (which, of course, work at different times) are lifted and turned by the same rods, made of pine 8 inches square, about 59 feet long, and

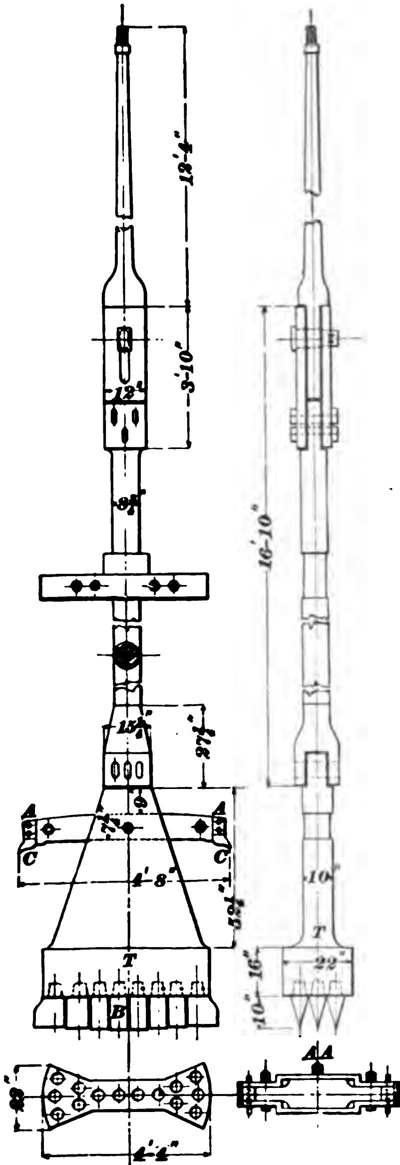


FIG. 459.

connected by a male and female screw. The elasticity of the wood with its buoyancy in the water gives them a great advantage over iron rods.

1533. The stroke of the cutting tool is effected by means of a simple lever at the surface, to one end of which the rods are attached by a strong flat chain, while near the other end the lever may be connected directly to the piston rod of a steam cylinder, as in a Cornish pumping engine. The length of this lever should be about 24 feet, and the fulcrum so placed that the ratio of length will give the desired stroke to the cutting tool. Beneath the suspension chain is a lengthening screw, and below that a very strong swivel, by means of which the rotating movement is given to the rods and cutting tool.

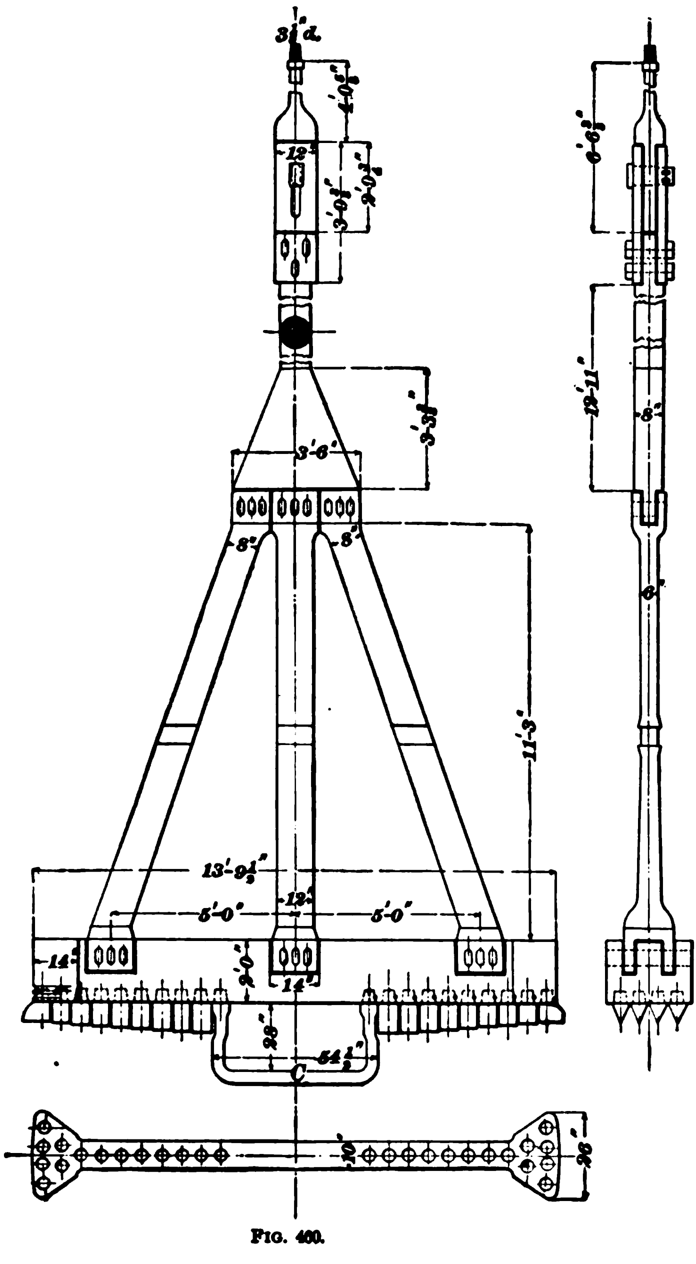
The upper piece of rod has eyes for the insertion of crossbars by which the actual turn is given at each stroke by the workmen near the top of the shaft. The smaller trepan, shown in

Fig. 459, is differently constructed, according to the nature of the ground it is intended to cut. When intended for cutting soft material, the bar in which the teeth are attached is suspended by a fork of wrought iron; but where hard rock is to be cut, the bar is to be forged in a single piece and weighs from 18,000 to 22,400 pounds. The steel teeth fit into sockets in the main bar, and are additionally secured by a pin, which is readily driven out when the teeth must be sharpened or renewed. The instrument shown in Fig. 459 is capable of advancing 8 feet per day in ordinary ground. The arm *A A* is for the purpose of steadying the motion of the machine and is slightly larger in diameter than the lower part *B*. The teeth *C*, *C* on the arm *A A* widen the hole slightly and trim off the edges.

1534. When the cutter or trepan has done work for some hours, usually at the rate of 9 or 10 strokes per minute, sometimes at about 20 strokes per minute, it is raised by a small hoisting engine, with a flat hemp rope 14½ inches wide by 2⅜ inches thick, and by the successive unscrewing of rods. The hole is then cleared by means of a sheet-iron cylinder, about 6 feet in length, with two valves in the bottom, which is lowered and raised by the rods. On being worked up and down and turned in the same manner as the cutting tool, the débris is drawn into it; and when it has sunk to its depth in the loose stuff, it is raised, the valves close, and the material is brought to the surface.

1535. The larger cutter, or trepan, Fig. 460, which weighs about 36,000 to 49,000 pounds, is similarly formed of a wrought-iron bar having teeth attached for that portion of its length which exceeds the diameter of the smaller excavation. It is guided below by a cradle or iron bar *C*, which fits closely within the smaller excavation.

The teeth are so formed and set that they always cut the bottom of this second stage into a sloping surface, so as to allow the fragments to roll into the smaller shaft, where they are caught in a sheet-iron bucket which has been previously lowered into it. The rate of progress in ordinary ground,



3" d.
4'-0⅝"
12"
3'-0½"
2'-0½"
3'-3⅝"
3'-6"
8"
8"
11'-3"
13'-9½"
12"
5'-0"
5'-0"
14"
2'-0"
14"
28"
54½"
C
10"
36"
0'-6⅜"
19'-11"
8"
6"

FIG. 460.

when all is going well, is about 40 inches per day; but in hard rock the rate will not exceed 10 inches per day.

1536. In order to obviate the tremendous vibration which would be imparted to the rods by tools of this great weight, a special arrangement is necessary in order that the heavy rod and cutting tool, which together are 36 feet long, may be "free falling," the balance of the rods being used simply to raise the cutter to the desired height of stroke. To accomplish this, a slide piece of great strength is used in a manner resembling the "jars" in the American rope method of boring.

The guides of the smaller trepan are set at right angles and formed of two strong iron bars. In the case of the larger trepan, one cross-piece only is rigid; the other one, at right angles to it, is hinged on both sides of the main rod in such a way as to be lowered or raised during the shifting of the tools. These folding arms, when required to be used, are brought into position when the tool is ready for work. The guide then forms a cross, through the central opening of which the rod of the tool slides freely up and down.

Figs. 459 and 460 show the dimensions of the tools for boring a shaft 14 feet in diameter.

1537. The most remarkable part of the operation is the fixing of the tubbing, Fig. 461, without the use of pumping engines, in such a manner that it securely dams back the water in the measures sunk through. The lower ring of the tubbing is, like all the upper portion, cast in a single piece. Its bottom flange *A*, which comes to rest on the bed or seat cut in water-tight ground, is turned outwards, and its upper flange *B* inwards. Upon the lower flange, and all around the ring, a wall of well-picked moss *C* is tightly packed. This moss is enclosed in network while being lowered to position. To aid in the forcing of the moss against the side of the shaft, small sheet-iron springs *D* are placed above and below, as seen in Fig. 461, which have the effect of giving the pressure a definite direction. The next ring *E*, which is large enough to slide down on the outside

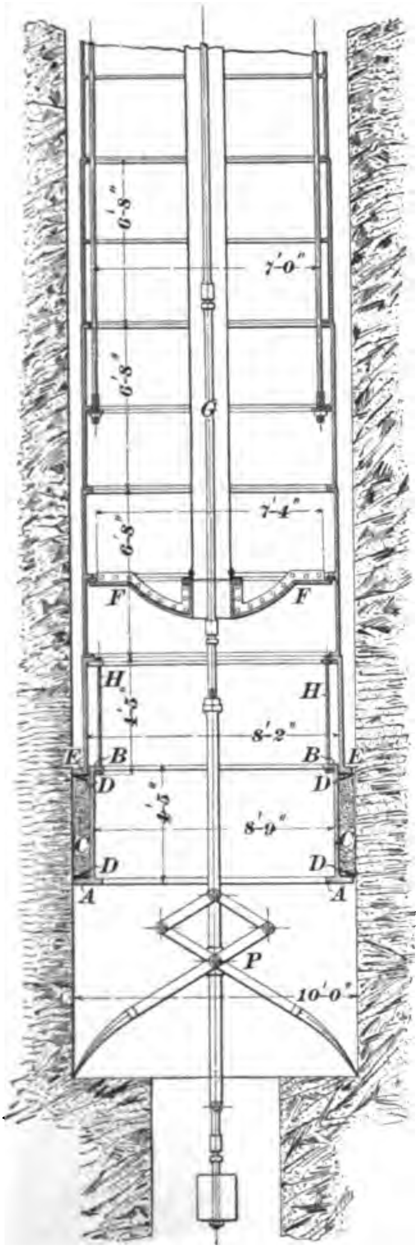


FIG. 461.

of the bottom piece, rests on the moss cushion by a flange also turned outwards. As soon as the moss is pressed down by the weight of the ring *E*, the ordinary rings of the tubbing are built upon it, as before, and their weight continues to compress the moss until it is practically solid. Each flange is planed, and between them a ring of sheet lead $\frac{1}{8}$ inch thick is laid, which, after screwing up the bolts, is beaten in on both sides with hammer and chisel.

The tubbing is of extra thickness, and each ring is generally made $4\frac{1}{2}$ feet to 5 feet high. The lower ring is $2\frac{3}{8}$ inches thick, and the upper ones are made gradually lighter. In order to facilitate the gradual lowering of this enormous weight by the six rods and screws used for this purpose, a diaphragm or false bottom *F* is attached by screw bolts near the bottom of the tubbing, which causes it to float on the water. A central equilibrium tube *G* passes up

the shaft, and stop-cocks, placed at intervals, allow water to flow into the middle of the tubbing in such a quantity as will help its descent. In this way only a small portion of the weight of the tubbing is carried by the suspension rods and screws.

When at length the moss box, hanging by light rods *H* from the flange of the upper ring, comes to occupy its position on the seat or bed, the weight of the tubbing above begins to bear on the moss and squeezes it down and against the sides in such a manner as to form a thoroughly watertight joint. For additional security, the annular space between the tubbing and the sides of the shaft is filled with concrete, which is allowed to consolidate before the water is drawn out of the shaft.

Much depends upon the perfection with which the seat of the moss box is cut and smoothed. For the purpose of ensuring its proper condition, a gigantic pair of pincers *P*, Fig. 461, with arms on the principle of a lazy-tongs, is lowered with and underneath the whole of the tubbing, having a rod passing up through the central or equilibrium pipe. The end of this tool can, by working the rod up and down, be made to expand to the full diameter of the shaft, and brought together so closely as to pick up fragments of stone or iron which may be lying on the bed of the shaft, and then in its contracted form may be passed out of the way into the smaller central shaft.

1538. After the cement has set, the water is pumped out of the pit, the false bottom is removed by unscrewing the bolts which attach it to a flange, the moss box foundation is examined, and to make everything safe, a lower seating is cut a few feet deeper, a wedging curb put in by hand, in segments, and a length or two of tubbing built up to the moss box, and securely wedged against it. The shaft is then free from water and ready for further sinking by the ordinary method.

By this method,

1. No pumping engine is required while sinking.

2. The water pressure in the shaft to a great degree prevents the inflow of quicksand or other soft material.

1539. The Lippman System.—In this system the hole is bored any required size from the beginning by a large trepan having a cutting tool bifurcated at both ends, or shaped like a **Y** at each end. This form of trepan, shown in Fig. 462, is adopted in order that the blows near the circumference will be approximately as close as those near the center. In this system, the engine gives motion to the boring lever by means of an endless chain and an eccentric, which prevents all shock. For removing the débris, an iron box divided into three compartments, each compartment having nine holes closed by valves opening inwards, is operated just as is the sheet-iron cylinder used in connection with Fig. 459. This iron box must generally be filled twice before boring can be resumed.

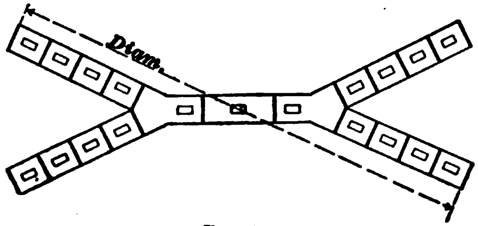


FIG. 462.

The sides of the shaft are secured in a similar manner to that employed in the Kind-Chaudron system.

THE LONG HOLE SYSTEM.

1540. This process consists of drilling holes from 100 to 300 feet deep, or more, and close enough to each other (3 to 4 feet apart) to be used for blasting. When the drills are taken out of the holes, the holes are filled up with sand. The sinkers then usually drill sumping holes in the center and blast out the rock. They then remove 3 or 4 feet of sand from the long holes. The inner group of long holes is always fired first, and the outside rows afterwards. The outside holes generally square the shaft nicely, so that little dressing is required. When the bottoms of the holes are reached, the drills are again put at work.

This method has been successfully carried out in the Norwegian shaft near Pottsville, Pa., which is nearly 1,600 feet deep, and at the Ellangowan shaft near Shenandoah, Pa. The drill holes were put down in stages of 200 to 300 feet by the diamond drill. The great objection to this system is that in rocks of varying hardness long holes are liable to turn from the vertical, and those nearest the side may fall outside of the line of the shaft.

DEEPENING SHAFTS.

1541. When there is plenty of room, so that a compartment of the shaft can be set aside for hoisting the débris, or where the regular hoistways can be used by sinkers at night, deepening a shaft is no difficult matter. If, however, the hoisting of coal goes on incessantly in a narrow shaft, then a rock slope must be driven to a point directly under the shaft. This slope must be started at such a distance from the shaft and driven at such an angle

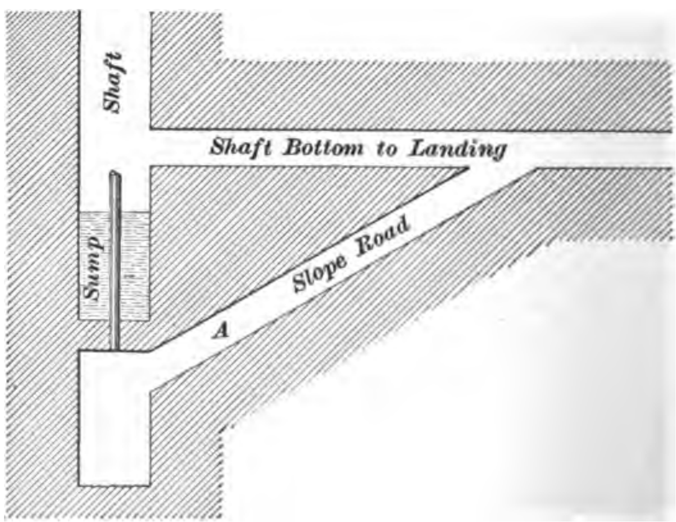


Fig. 463.

that, when it is directly under the shaft, the strata between the slope and the bottom of the sump in the shaft will be

thick enough to ensure that the water will not pass through it. Then, from the foot of this stone slope, the sinking of the shaft may begin. (See Fig. 463.)

In this case, a hoisting engine or a windlass must be used in the rock slope to get the cars out of the shaft and up the incline *A*; or a bore hole may be put down in the shaft bottom and a pipe inserted with cement. The top of the pipe should be above the water level in the sump. Through this pipe, the hoisting rope is passed to an engine at the surface by carrying the rope up the side of the shaft.

1542. Where one compartment can be used for hoisting the débris, the shaft is carried down narrow to a depth that will ensure strength in the rock to maintain itself and hold the water; then the full length and width is carried down. The sump in the old shaft bottom is maintained by putting in a secure dam to keep the water confined, so that it will not pass into the sinking shaft. Sometimes, when the depth is not very great, the whole width is carried down, and the water is all pumped to the surface from the point of sinking. In this case, the bottom of the landing, from which the coal is hoisted, is made of a close framework strong enough to protect the sinkers while working.

WIDENING SHAFTS.

1543. This is sometimes necessary, but it is practised so little that information on the methods employed is scarce. It is an awkward and costly operation, and must be done when the shaft is not in use. It is usual to place a series of buntons below each other in such a position that the cages in passing up and down will not strike them. When the hoisting is discontinued, planks are laid on these buntons, making a secure scaffold on which the men stand to remove the strata, and, if necessary, put in new timbers. The work, more especially in soft strata, seems to give best results when the start is made at the top of the shaft, and the work carried downwards.

CONDUCTORS, GUIDES, OR SLIDES.

USE OF GUIDES.

1544. These three names are different terms applied to the arrangement in shafts for preventing extreme oscillation or vibration of the moving cages, so that two or more of them can run in opposite directions in a comparatively narrow place without colliding with each other. They also keep the cages from striking the sides or ends of the shaft. There are various kinds and arrangements of conductors, either rigid, of iron or wood, or flexible, of strong wire rope.

When there are column pipes in the shaft, and consequently many buntons and horsetrees to which the rigid guides can be secured, such guides will give the best results, and it is only under these conditions that they should be employed.

WOODEN GUIDES.

1545. When wooden guides are used, they are placed one on each side of the cage and are attached to the buntons in a vertical line by countersunk bolts or wood screws. They are made of pitch pine, the dimensions varying from 4 inches by 4 inches to 6 inches by 8 inches. The manner of splicing or joining the lengths has already been shown.

The utmost care must be observed in splicing, for even a small projection may catch the shoe of the cage and result in the destruction of some part.

1546. Point Rods.—Point rods are necessary only in exceptional conditions, such as when the buntons and other timbers are placed so that it is desirable to have the guides at the ends of the cage, and the cars are caged from the same direction. Slippers, or shoes, when point rods must be used, are placed on all four sides of the cage. When the cage is in any part of the shaft, excepting top and bottom, the shoes at the ends are in contact with the guides at the ends of the shaft. The end guides are discontinued near the top and bottom, and are replaced by the point rods, which engage with the slippers on the sides of the cage before the

end guides are discontinued. If the guides are rods, they are pointed, or if of channel iron, they are belled out at their termination, so that there will be no doubt about the shoes engaging the guides.

Sometimes, the side guides and slippers are replaced by angle iron guides, which are so placed that they will engage the four corners of the cage; these guides are also belled out.

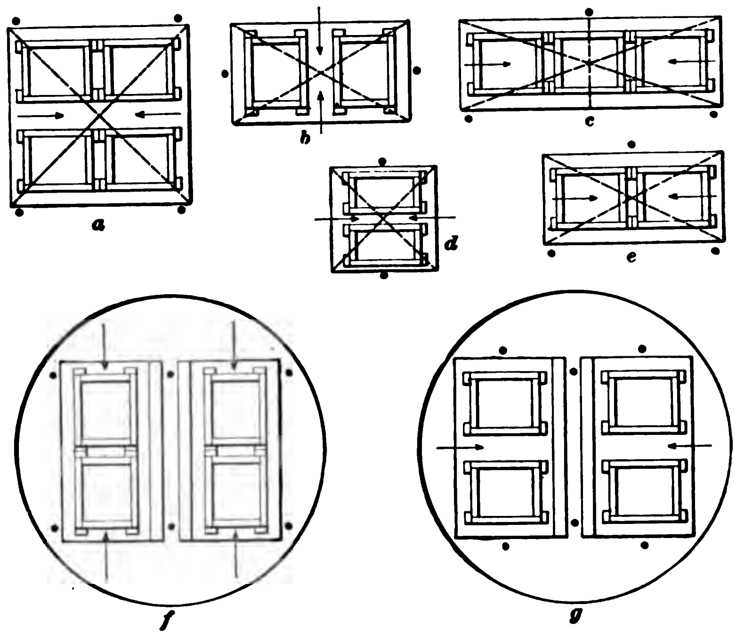
IRON GUIDES.

1547. These may consist of channel iron, structural **T** iron, round iron, or **T**-iron rails. The first two—channel iron and structural **T** iron—are held in position by bolts or wood screws in much the same manner as the wooden guides. The holes in the iron are countersunk so that the head of the bolt or screw can not by any means protrude. It is almost impossible to make the proper arrangement for expansion and contraction in such guides, which is a strong objection to their use. Expansion and contraction are sometimes provided for by leaving a small space between the ends of the guides at each joint. The slippers are made of a pattern that will suit the particular arrangement that is used.

1548. Round Iron Guides.—These consist of bars of 1-inch or 1¼-inch round iron extending from the top to the bottom of the shaft. They are held in position by being secured at the top and bottom on heavy cross-timbers, and are kept taut by turnbuckles—a right and left screw—located at a place convenient for observation and manipulation either at the surface or at the bottom of the shaft. Or the rods may pass through a hole in the bottom timber, and weights be suspended to them heavy enough to keep them taut. The latter plan, in many cases, is the better one, inasmuch as expansion and contraction are provided for.

1549. T-Iron Rail Guides.—These are used to get the rigidity of wood and avoid rapid wear. They are quite expensive; therefore, their use is the exception and not the rule. The flanges of the rail for this purpose are usually made broader than the ordinary construction, and are fitted

into chairs made fast on the buntons and on the sides of the shaft timbers. The rails should be fastened together by fish-plates attached to the back of the rail. In such a case



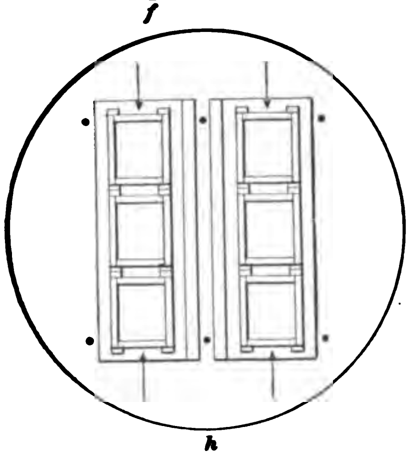


FIG. 464.

the joints are between buntons. A small space should be left between the ends of the rails at the joints for expansion, and the holes in the fish-plates should be made oval, so that the bolts are free to move up and down, as required by expansion and contraction, without any lateral play.

1550. Wire Rope Guides.—Where wire rope conductors are used in deep shafts, the clearance must

be more than with rigid conductors, because of the vibration that is set up in the guide ropes by the running cages.

Fig. 464 shows the various arrangements for wire rope guides for the different arrangements of the cages.

At *a* is shown a cage with four cars and four wire conductors; at *b* is shown a cage with two cars and two conductors; at *c* is shown a cage with three cars and three conductors; at *d* is shown a cage with two cars and two conductors; at *e* is shown a cage with two cars and three conductors; at *f* is shown two cages with two cars each and two conductors each, and flat rope or safety conductors between. Two conductors, both on one side of the cage, are used, and between the cages, and unconnected to either of them, two other ropes are suspended. These latter ropes are often flat (not always), and at the passing point are lined or covered with steel or copper strips which prevent any possibility of the cages colliding when the clearance is very little. At *g* is shown two cages with two conductors each and two cars each; at *h* is shown two cages with three cars each and two conductors each.

The arrows show the direction in which the cars are run on to the cage, and the dots show the position of the guides. The dotted lines show the position of the cage chains.

1551. Wire rope conductors, like T-rail and other iron guides already mentioned, are subject to expansion and contraction. This is provided for in the following manner: Each conductor is made secure at the top of the head-frame with two or more wrought-iron clamps. These clamps grip the conductor and rest upon timbers of sufficient strength to safely carry the greatest weight necessary to keep the conductors taut. Care must be exercised in fitting the clamps nicely to the guides; otherwise, instead of holding the conductors firmly, the clamps may actually nip and tend to break them.

At the lower end, in the sump, heavy weights are placed upon clamps, one or two pairs gripping the conductors. The weight varies according to the depth, but a fair rule is 2,240 pounds for each 600 feet of the depth.

The rope should not, as in the case of the round iron guides, run through a hole in a bottom sill, but the bottom sill should be so arranged that heavy staples may be driven into it over the rope. This avoids corrosion of the rope by water and dirt settling around the guides in the timber. It also permits the rope to be examined there as well as in other parts of its length. Care must be taken to see that the weights always hang freely on the conductors. These ropes should be thoroughly examined once each week.

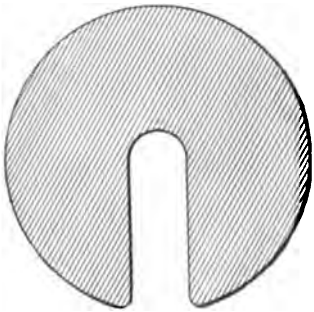


FIG. 465.

It is not possible at all times to put on the exact weight that will be required; consequently, there should be a number of extra circular weights, Fig. 465, with a slot from the center to the circumference in each, so that they can be slipped on top of the weights already hung on the rope.

SLOPES.

SLOPE SINKING AND TIMBERING.

1552. In mining, the term **slope** is applied to an inclined gallery or roadway driven through the measures to a seam of coal; or, where the seam is pitching, a passageway driven in the coal towards the dip is also termed a slope.

Where a seam has a dip of 20° or more, and is brought close to the surface by an anticlinal axis, a slope, dipping the same as the coal, may be started from the surface, and when the seam is reached may be continued to the desired depth in the coal. If a seam is comparatively flat and near the surface at the desired place of opening, it may be opened up by a **shaft** or **slope,** depending largely upon the individual choice of the engineer in charge.

A slope and an air course are generally sunk side by side in the coal; but, where the slope passes through the overlying strata, a shaft is sunk near by to serve as an airway.

1553. In commencing a slope, the ground is excavated in an open cut, precisely as a railroad cut is made, the sides being trimmed back to the angle of repose, or made perpendicular and supported by crib work. The excavated ground is thrown out by hand or removed by wheelbarrows. When the face of the cutting has a greater vertical height than the total height of the timber to be used, the sinking of the slope is commenced in the following manner:

Sufficient room is first excavated for a set of timbers in advance of the one set up where the open cut was discontinued. Where the ground is friable, as it frequently is at

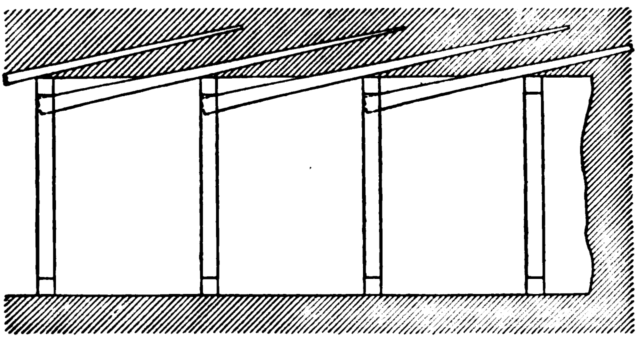


FIG. 466.

shallow depths, lagging of timber (usually 3-inch or 4-inch plank on top, and 2-inch or 3-inch plank on the sides in well-finished work) is securely placed. The lagging is made flush with the front of the first set of timbers, but on each set thereafter, it reaches from center to center. Sometimes, the ground is so soft that **forepoling,** or piling driven in the roof in advance of each set of timbers, is employed (see Fig. 466), so that the timbers can be put in without removing an unnecessary amount of material.

1554. Frequently, the overhead lagging is put up by cutting a trench from the top to the bottom of the face of the slope, from 12 inches to 18 inches wide, the one end of the lagging board resting on the last set of timbers, and the forward end resting on a temporary prop of suitable length.

When this prop is secured in place, another slice is cut on either side of this single top lagging and another plank put in, and so on till all the top lagging is in, with the forward ends resting on props and the back ends on the last set of timbers. The temporary props should slant inwards towards the face at the bottom, so that the "foot" or mud-sill can be put in without disturbing them. The mud-sill is now put in place, and the set of timbers put up sloping backwards on the head; the set is now driven forwards to the props, which are removed, and the complete set of timbers is carefully driven forwards and lined in place.

When necessary, the sides may be secured in the same manner as the top is secured in Fig. 466.

The distance these sets of timber shall be apart is, of course, governed by the nature of the roof, and may range from "skin to skin" (Fig. 472) to 8 feet apart.

1555. The dimensions of a slope depend upon the number of tracks to be laid in it and the size of the mine car. In some districts, the average capacity of the cars ranges from 2,000 to 3,000 pounds, and they measure about 4 feet in width, while in other districts cars carrying from

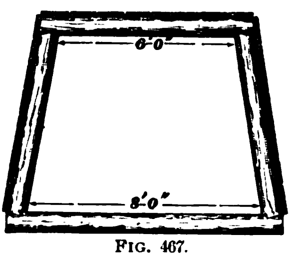


FIG. 467.

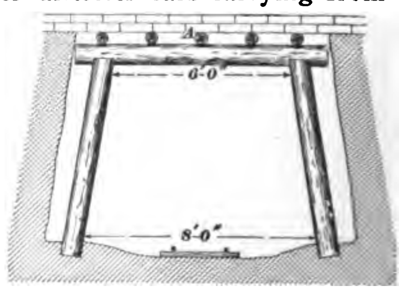


FIG. 468.

2 tons to 4 tons are used, measuring as much as 5 feet in width.

In short, with single track slopes, where the cars do not measure more than 4 feet in width, a style of timbering such as is shown in Fig. 467 may be used.

Fig. 468 shows how timber framework, after being placed in position, can be firmly wedged against the roof with lagging *A*.

1556. Where the legs are stood without a mud-sill or foot-sill, each leg must be measured. The foot-hole having been dug, a light stick of wood is nailed from the last two sets of timbers at the proper angle to project the proper distance, and the length of the leg required is measured from the point of this stick to the bottom of the hole by a sliding measure of two thin strips of wood which act as a measuring rule. This requires care, or the timber will get out of line, or some will be higher than others. With round timber, small differences are not easily seen, but with square timber any irregularity will be noticed quickly.

1557. In slopes where the output is large, a double track is usually adopted. In such cases, the double track may be laid with three rails and a "turnout," or passing place, at the middle of the plane, or it may consist of two distinct and continuous tracks throughout the length of the plane. The former plan has the advantage of minimizing the width of the slope, but is open to several objections, the principal of which are the liability of collision of the ascending and descending trips, or trains, at the passing place, if there is more than one landing, and the wear and tear of the rope, which, by reason of the lateral movement due to the travel of the coil on the face of the drum, must at certain places chafe against the cars, the rope on the one side being impelled against the cars attached to the opposite rope. In every case where double tracks are needed, it is preferable to lay down two independent and continuous tracks.

1558. Where a double track is in operation, the slope must be from 12 feet to 24 feet wide in the clear, depending on the size of the car to be used and the number of compartments in the slope. It is rare in a slope of such width that the roof or top is firm enough to stand without the aid of timber, which frequently must be placed at close intervals. Fig. 469 shows, in section, the timbering of a double track slope. The prop placed under the center is fixed between the two roads, and the collar and legs are closely

lagged all around so as to prevent any fall or slip of the roof or sides. The timber generally consists of sticks from

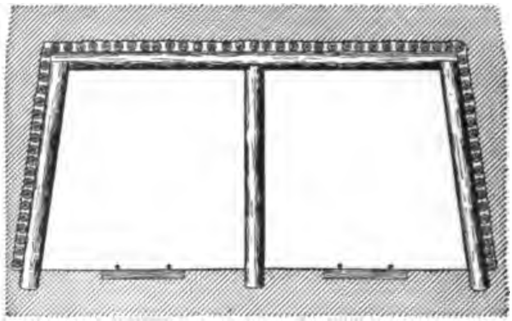


FIG. 469.

9 inches to 14 inches in diameter. In many instances, more substantial timbering is adopted, and beams ten inches to fifteen inches square are used instead of the round collars and

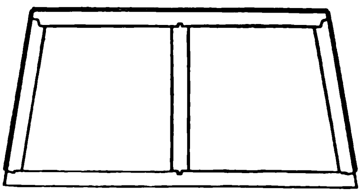


FIG. 470.

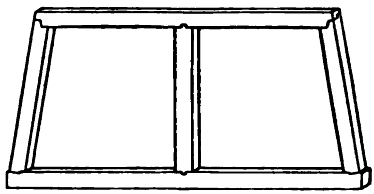


FIG. 471.

legs, and they are lagged with planking instead of poles, as described. This form of timbering is shown in Figs. 470 and 471.

Fig. 472 shows the "skin to skin" method of timbering, so called because the sets of timber touch each other. It is used in soft ground where the pressure is very great. The figure shows round timber, but square timber is sometimes used in this manner.

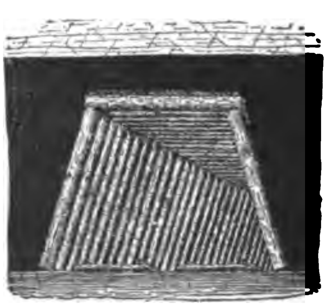


FIG. 472.

1559. Fig. 473 shows the double notch in the mud or footsill of Fig. 471. The leg *b* is placed to show the check which rests on the sill *a* to prevent slipping. The step in the box prevents the leg from slipping

down off the sill, and the check on the front holds down the top

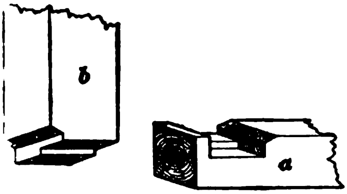


FIG. 473.

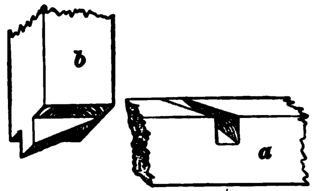


FIG. 474.

surface of the sill when the weight sinks the leg tight into it.

Figs. 474 and 475 show the groove in the sill *a* and the

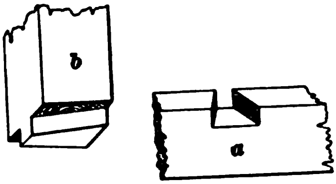


FIG. 475.

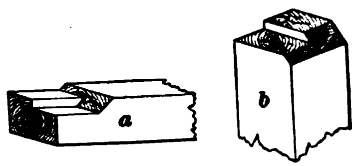


FIG. 476.

tongue on the leg *b* to prevent the leg from being driven down the pitch.

Fig. 476 shows a view of the leg *b*, and represents the collar *a* turned up, showing the double notch to prevent it slipping down the pitch.

Figs. 477 and 478 show another style of joining by tenon

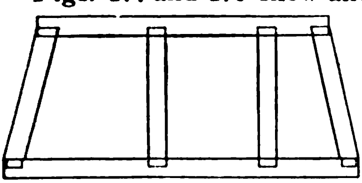


FIG. 477.

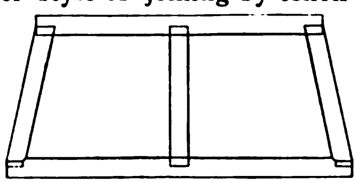


FIG. 478.

and mortise, but the great objection to it lies in the fact that the legs are not easily removed when retimbering is desirable.

Figs. 479 and 480 show the manner the mortises and tenons in Figs. 477 and 478 are made.

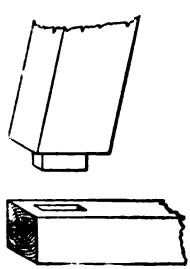


FIG. 479.

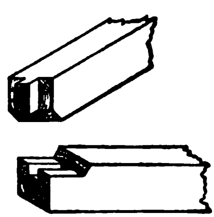


FIG. 480.

1560. Fig. 481 shows the provision made to keep the track in place, that is, to prevent it from slipping down the pitch in the slope. The long ties are shown resting against the legs in the lower portion of the figure; the middle shows the arrangement of the roadbed when only a center prop is used, and the upper part of the figure shows the arrangement when no timber is used; *a a'* are long ties, *b b'* are the regular ties, and *c*, *c*, *c* are braces to keep the ties in proper place.

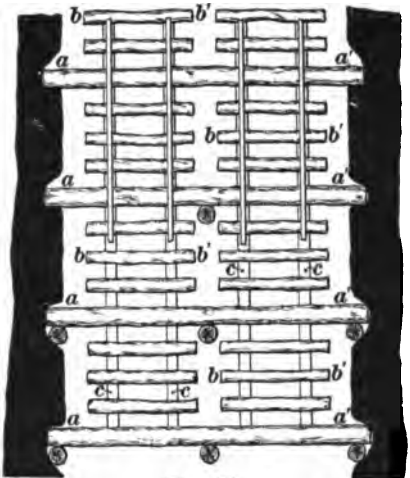


FIG. 481.

When square sets are used or where the sills of round sets are hewed on the upper side, a long tie is spiked upon it, or the sill itself may take the place of *a a'*, but this requires greater care in ballasting and "lining up" the tracks.

1561. Where the dip does not exceed 40°, the height of the slope is made about the same as the height of the entries or gangways, but it is never desirable to have the height less than about 6 feet.

Slope timbers are set leaning up the pitch a few degrees less than right angles to the dip, for reasons given hereafter.

1562. There are many methods of jointing timbers, but those given are as good as any forms in common use.

In the notching of timbers, there is a general principle of right and wrong. The joints should be cut so that every square inch shall have a uniform bearing. If the joint is poorly fitted, the whole weight will be thrown on a small surface, which will give way.

Care must be taken not to reduce the strength of the set too much by having too much spread, or batter, on the legs. Just what the batter should be is a debatable question, but it should not exceed 1 in 6 or 1 in 5.

1563. Where it is necessary or desirable to dispense with the center prop of a wide set of timbers, the following methods (Figs. 482 and 483) are employed. Besides the

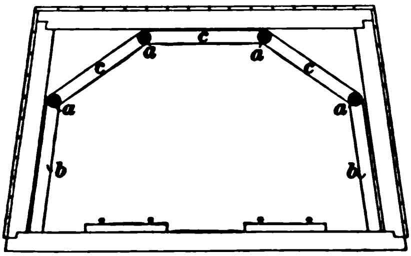


FIG. 482.

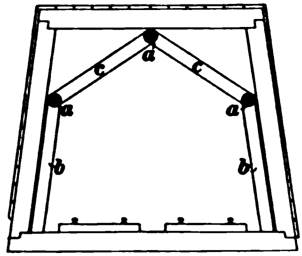


FIG. 483.

usual set of squared timber, there are pieces *a*, *a* running along the slope, with props *b*, *b* and braces *c*, *c*, the whole, as shown, approximating to the form of an arch.

WALLING.

1564. When the price of timber becomes more than that of brick, or where timber strong enough to give the

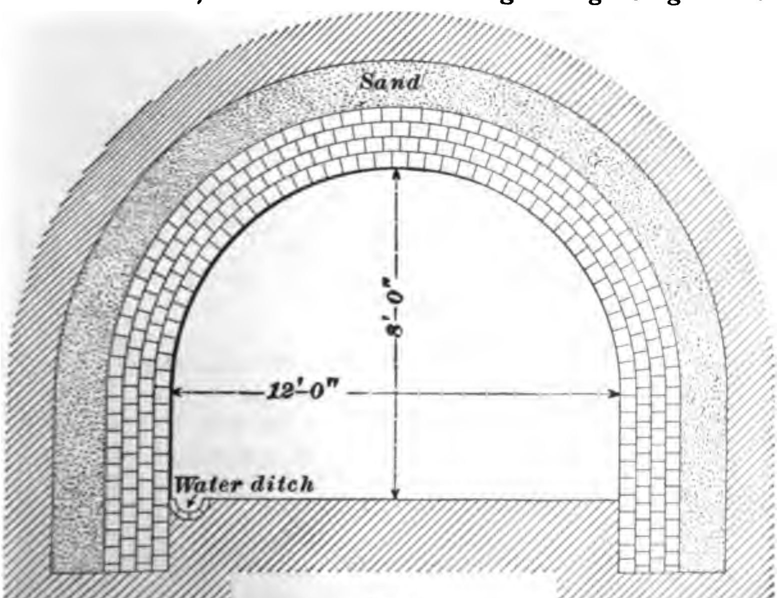


FIG. 484.

required room and security can not be placed, a stone or brick arch is built. When the bottom is hard, but the top is friable, the construction shown in Fig. 484 will meet the requirements; but where the ground is all weak, the method shown in Fig. 485 will give the best results. In building these, sometimes the side walls are built of stone and the arch with brick. The thickness of the masonry will depend upon the

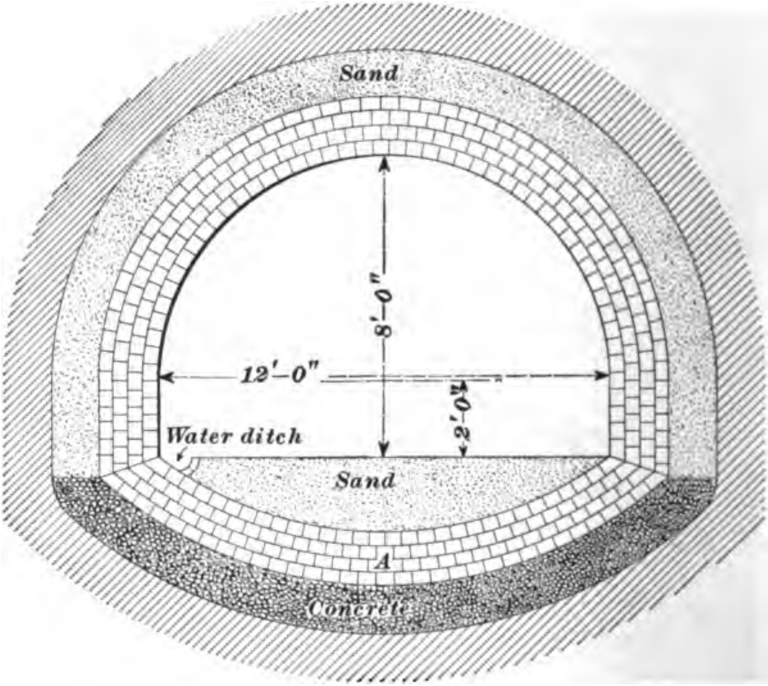


FIG. 485.

nature of the brick or rock used, but should never be less than 9 inches to 12 inches. Figs. 484 and 485 are for double roads where a wide car is used. When the structure has an inverted arch A, the invert is kept in advance of the side walls and the arching is built upon it. When an invert is used, the masonry is in three stages of construction, viz., invert, sides, and arch. When there is no invert, then there are only two stages.

Instead of the usual wooden templates, or frames (curved

frames which have the form of the invert and arch), iron templates are used for turning the invert and arch.

Where a heavy lateral pressure is expected, the sides of

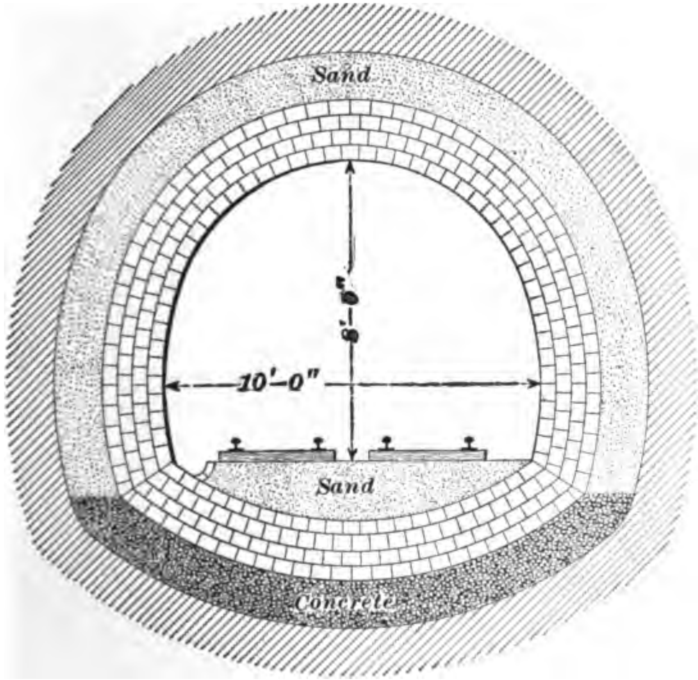


FIG. 486.

the arch should be concaved from their intersection with the invert, as shown in Fig. 486.

Fig. 487 shows an elliptical arched roadway, which is the strongest form that is suitable for mine roads. The circular is not practicable. The elliptical form will resist pressure from any or all directions better than any of the other forms given.

1565. Very little mortar should be used between the joints when building any one of these forms of arches. No old wood or anything subject to decay should be put in or left behind the walling. When there is considerable water in the strata, the space behind the walling should be filled in with concrete. At great depths the crush is enormous,

and arches of great strength are thereby destroyed. It has been found that by packing the top and sides with sand to a

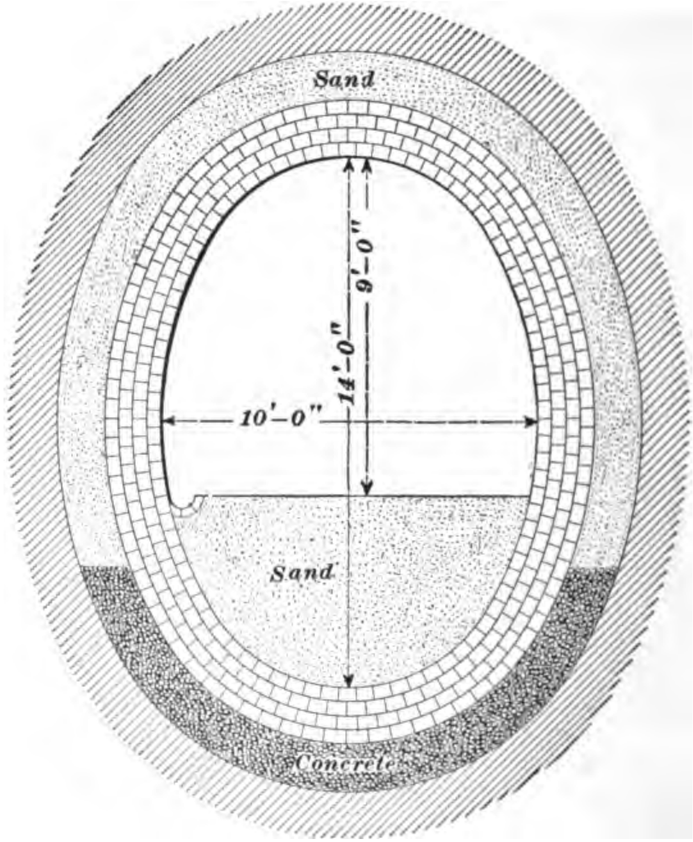


FIG. 487.

thickness of not less than one foot, the weight is distributed over the whole surface of the arch; consequently, it will stand a greater pressure.

SINKING OPERATIONS.

1566. In slope sinking, the operation of getting out the coal is accomplished in the same manner as when driving entries or gangways. The face is advanced by blasting out of the solid by means of flanking shots, alternating from one side to the other. Where the coal is hard enough to

blast, but not too hard to shear, the coal is "shorn" in the center from top to bottom and the coal on either side of this shearing is blown off the solid. In soft coal it is necessary to mine the coal, which may be done on the top or bottom, as the water will permit.

1567. In thick seams, where water is coming in freely, the upper portion of the coal is removed in advance of the bottom, the coal left forming a sump for the water. This lower coal may be advanced by leading the water to a small hole dug in the bottom, from which it is drawn by the pump, until the shot has been placed and fired. In thin seams this method is not practicable. Here some small proportion of the whole width must be kept in advance, either in the center or sides, from which the water is pumped. When there is no water, slope sinking is comparatively an easy matter.

1568. In "rock slope" sinking, the operation is on much the same principle. When air drills are used, however, the center is usually advanced first. A great deal depends on the judgment of the sinker in charge, and his skill may change the manner of procedure from time to time in order to get the benefit of natural advantages.

The tracks, together with the timbering or walling, are carried forward simultaneously with the sinking.

DRIFTS.

1569. A horizontal, or nearly horizontal, opening driven in the coal from the surface above water level is termed a **drift.** When the seam of coal dips slightly inward, instead of starting the drift in the coal at the outcrop, it is best to start it some distance below and give it such a grade that when the drift is driven far enough for the first "parting" or "turnout," it will have reached the bottom of the coal seam. In this way an easy grade can be made for the loaded cars, whereby the haulage from the main parting to the tipple will be greatly facilitated. The cost of opening a drift in this way is but little greater than that

where the coal has a good natural pitch for haulage and drainage, except when the underlying strata are very hard, and even then the lasting advantage, accruing from a grade in which gravity assists the loaded cars, more than counterbalances the increased cost of properly grading the drift.

1570. When it is found advantageous for haulage and drainage to open up a coal field along its outcrop, where sufficient height can not be obtained below the level of the coal seam for the tipple, the difficulty is overcome by means of an inclined trestle plane, up which the coal is hoisted from the drift mouth to the dumps on the tipple. Sometimes under these circumstances the opening is made far enough above the level of the coal seam to secure sufficient height for the tipple, and it is driven down to the coal. In such a case the opening would be termed a *slope.*

1571. The location of a drift is partially determined by the outcrop; otherwise, it is fixed by the same conditions which determine the location of a shaft or slope.

Drifts are largely used in the bituminous region of the eastern part of the United States, and also in the anthracite region where the seams are exposed in ravines or gorges across the strike of the coal measures.

Where it is possible to open a coal field by a drift, it should be done, because both pumping and hoisting machinery can be dispensed with.

1572. Drifting is advanced in the same manner as a slope, both in regard to timbering and excavating the strata. The operation is, however, much easier, because the drift is of such a grade that the water will run away from the face and not trouble the workmen, and the timbers are set vertically.

In the bituminous fields there are usually two drifts, driven into the coal parallel to each other, one of which is used for the main haulage way, and the other for an airway, in front of which is placed the fan.

METHODS OF WORKING COAL MINES.

(PART 1.)

PILLAR AND CHAMBER METHODS.

SHAFT PILLARS.

1573. There are necessarily a great many methods of working coal mines, because coal not only varies widely in its physical properties, but is found in different strata, and at different depths and inclinations. All the methods, however, may be classified in a general way under two principal divisions, viz.: *Pillar and Chamber* and *Longwall* methods. Either of these two divisions may be so modified as to make it difficult to determine whether the modified method should be called Pillar and Chamber or Longwall.

1574. After a shaft has been sunk to the seam, the levels, entries, headings, gangways, or galleries to communicate with every part of the territory to be mined are turned off. Whatever the method adopted, no coal should be mined for a certain distance around the shaft except for the opening of roads. The pillars thus left should be large enough to protect the shaft from rupture.

1575. The size of the shaft pillar depends on:

1. *The Depth of the Seam.*—Because the pressure of the superincumbent strata increases with the depth.

2. *The Inclination of the Seam.*—Because the plane of fracture lies between the vertical and a line drawn at right angles to the pitch, and what is known as the "zone of subsidence" diminishes in height as the pitch increases.

The working of a seam causes the overlying strata to settle, and produces what is called "subsidence." If the seam is horizontal and not too deep, this subsidence will reach the surface and be greatest at a point vertically over

the center of the excavation; but, if the seam is deep-seated, the settlement may not be perceptible at the surface. In case the subsidence reaches the surface, its limits bound what is called the **zone of subsidence.** If it does not reach the surface, a dome is formed, and we have what is termed the **dome of subsidence.** When the strata are homogeneous and horizontal, the dome of subsidence is symmetrical and its axis is vertical; but when the strata are inclined, the dome is not symmetrical and its axis is inclined. As the inclination of the strata approaches the vertical, the height of the dome becomes less. When the zone of subsidence crosses strata of varying inclinations, the axis of the dome is deflected; and, if the strata are soft and loose, the dome may reach far beyond the limits of the excavation, especially if the strata contain water. In all cases the plane of fracture of stratified rocks lies between the vertical and a line perpendicular to the strata.

3. *The Nature of the Overlying and Underlying Strata.*—Because the nature of the strata affects the *domes* variously, that is, the hardness, elasticity, plasticity, compressibility, etc., are conditions which affect the result. If the rocks are hard and brittle, the fall increases in volume much more than if they are plastic. If they are firm and cohesive, they yield only under forces very much greater than those which suffice to draw away soft strata. If it has elasticity, it transmits to a greater distance the pressure which it receives. The compressibility of rocks after expansion is also very variable. Therefore, over identical excavations domes are formed which differ in length, height, and width. When water is present with a soft fireclay bottom for the seam, it makes the protection of the shaft more difficult. The excessive pressure on the pillar of coal compresses the fireclay and also forces it up on the roadways, from which it must be removed; the process may go on indefinitely if the pillar is not very large, and may eventually destroy the alinement of the shaft.

4. *The Texture of the Coal.*—Because harder coal can withstand more pressure without crushing than softer coal, and is not so much affected by atmospheric influences.

5. *The Thickness of the Seam.*—Because the dome of subsidence, as a rule, develops in breadth and in height with the height of the excavation; however, there seems to be no direct ratio in the amount of subsidence to the height of the excavation.

It follows from the above considerations that in pitching seams the rise side pillars should be the larger, as shown in Fig. 488. Here, a much larger pillar is shown on the rise side than on the dip side of the shaft. The vertical lines are shown dotted at *a b* and *a' b'*, and the lines at right angles to the dip are shown dotted at *a c* and *a' c'*. The lines of fracture are shown solid between the dotted lines. On the rise side, the line of fracture approaches the shaft, while on the dip side it goes away from the shaft.

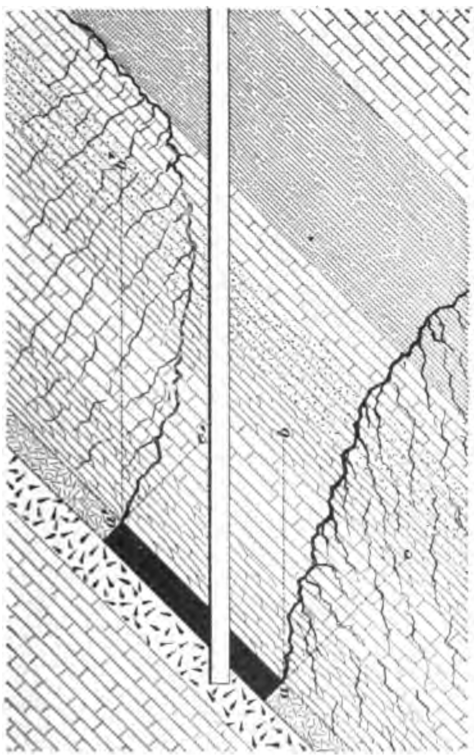


FIG. 488.

There is, perhaps, no point in mining on which so much diversity of opinion exists among authorities as on the size of shaft pillars required under given conditions. Any accident to the shaft caused by a pillar of insufficient size entails great expense and loss of output, and it is better, therefore, to err on the side of safety in this matter.

1576. *The size of pillars is generally determined by experience in the district in which the shaft is sunk.* The measurement of the pillars in many successful shafts indicates that the radius of a circle representing the minimum area of the shaft pillar should be (in flat seams) about one-fourth of the depth of the shaft, for shafts less than 700 feet deep. That is, a shaft $533\frac{1}{3}$ feet deep should have $\frac{533\frac{1}{3}}{4} =$ $133\frac{1}{3}$ feet of solid coal all around it; or, with the shaft as a center and with a radius of $133\frac{1}{3}$ feet, describe a circle within which no coal (excepting for necessary passages) should be mined.

There are, at most shafts, heavy winding and pumping machinery, machine shops, etc., and it is important that the draw, or disturbance of the strata, should not reach them. If these are close to and all on one side of the shaft, the radius on that side should be increased to the distance these buildings extend from the shaft, provided the shaft is less than 700 feet deep. For example, if the buildings extend 100 feet from the shaft on one side, then the radius on that side should be $133\frac{1}{3}' + 100' = 233\frac{1}{3}$ feet. Again, if the buildings are on all sides of the shaft, the furthest one being 100 feet from the center of the shaft, the radius should be increased just that much; or $133\frac{1}{3}' + 100' = 233\frac{1}{3}$ feet will be the radius with which to describe a circle from the shaft as a center. This circle marks the pillar reservation.

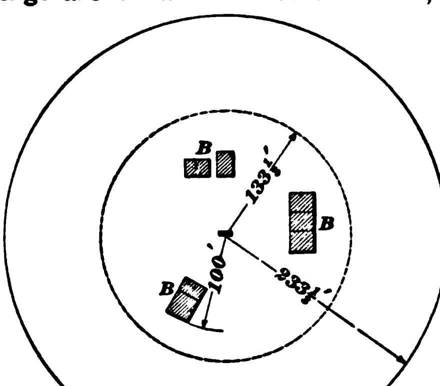


FIG. 489.

The dotted circle (Fig. 489) shows the area of pillar left to protect the shaft only, and the great circle shows the size of the pillar necessary to

protect the shaft and the buildings B, the furthest being 100 feet from the center of the shaft.

1577. For shafts deeper than 700 feet, a good formula for determining the approximate size of shaft pillar under average conditions is: radius of shaft pillar $= 3 \times \sqrt{D \times t}$, where $D =$ depth of shaft, and $t =$ thickness of seam. Thus, a shaft 900 feet deep, which is sunk to a seam 8 feet thick, should have a pillar whose radius $= 3 \times \sqrt{900 \times 8} =$ 254.56 ft. When a shaft exceeds 700 feet in depth, it is seldom necessary to provide extra pillar for buildings, unless the seam is extraordinarily thick.

Great care should be exercised in determining the size of shaft pillars in districts where experience has not already determined the best dimensions.

SLOPE PILLARS.

1578. These pillars depend on the five principal points mentioned in speaking of shaft pillars. However, there is not much danger of the draw destroying the slope, because the line of the slope is nearly at right angles to the plane of fracture, whereas in a shaft, the line of the shaft and the plane of fracture converge in pitching seams.

1579. By assuming that a mass of strata receives no support by virtue of its own strength or adhesion to the surrounding strata, which is true over large areas, it may be inferred that pillars will be subject to weights varying directly as their depth from the surface, multiplied by the cosine of the angle of dip. Therefore, pillars should increase in size as the slope advances downwards. What the exact increase should be can not be determined definitely enough to warrant the formation of a rule.

For a close approximation of the size of pillars required at the bottom of a slope, when conditions are normal, the formula $3 \times \sqrt{D \times t}$ (see Art. **1577**) may be used, in which D should represent the *vertical* depth of the slope below the surface, and t the thickness of the seam. The

pillar on either side should not be less than 50 feet wide at any point.

Squeezes on slopes are of frequent occurrence. This indicates that the usual practice, which does not provide for the increasing pressure due to increasing thickness of strata, is faulty.

1580. When the strata immediately overlying the coal seam are comparatively brittle and fall into the excavation, considerable weight is taken off the adjacent pillars, and when the fallen débris is sufficient to fill the opening, it also supports, to some extent, the overlying strata. If the overlying strata are strong, and do not break, the adjacent pillars must not only support the strata immediately overlying them, but the strata overhanging the worked-out portions as well. Therefore, to avoid a squeeze, larger pillars are required under a strong roof than under a brittle one. If the top is hard and strong and the bottom soft, still larger pillars are required to prevent, as much as possible, the squeezing of the pillars into the bottom.

In any case, if ample pillars can not be left in to completely support the roof, it is best to induce a fall of the strata if possible, so that the weight may be lessened and that the expanded débris may take a portion of the weight off the pillars.

1581. The slope pillars in no case should be less than 100 feet wide, and in many cases they are 200 feet wide. This latter width includes all passages, usually two, sometimes three, and occasionally four—all parallel with each other. The laws of Pennsylvania require at least 60 and 30 feet, respectively, in the anthracite and bituminous regions, between main passageways.

Fig. 490 is a plan showing two slopes with parallel airways; *s s* is the advancing or sinking slope; *h h*, the hoisting slope; *a*, *a*, the airways, and *r*, *r*, the rooms.

1582. Shafts should be sunk so that the track on the cage will be parallel with the strike of the seam. This permits the running of the mine cars on the cage direct from

the mine tracks. Slopes should be sunk on the full dip of

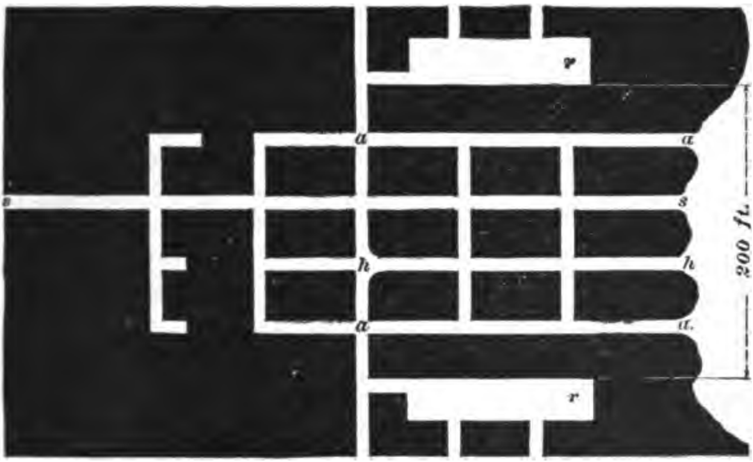


FIG. 490.

the seam, to secure stability of track and convenience at the bottom landing.

SLOPE LANDINGS AND SHAFT BOTTOMS.

1583. When the slope is driven on the full dip, the landings or turnouts are usually made on each side on the strike of the seam. Beginning at a short distance from the slope, the gangway is widened out to from 12 to 20 feet, or more, depending on the space required for men, mules, cars, etc. It is carried forward at this width far enough to accommodate such a number of cars as will ensure a constant supply to handle the coal in that lift. When the top is weak, these landings must be timbered in pretty much the same manner as the slope. When the gangways or headings are driven at a sufficient distance from the slope, turnouts are made exactly the same as the landings. On these turnouts the loads are collected and hauled in larger trips to the landings. As the loaded and empty cars have their special tracks, spring-latches are advantageously used at both ends of the turnouts.

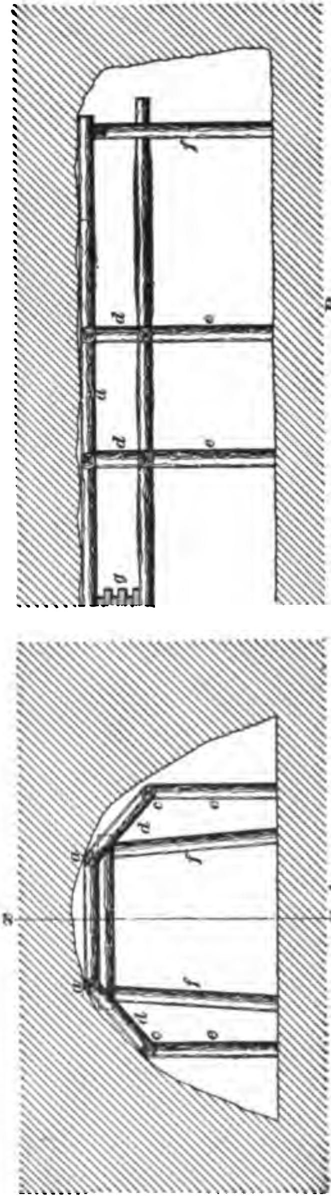


FIG. 491.

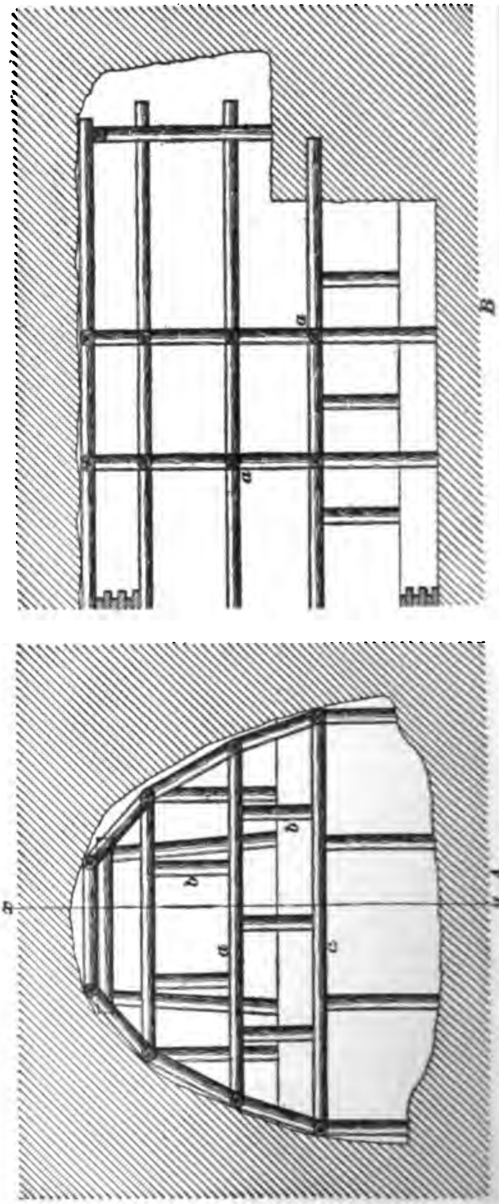


FIG. 492.

1584. Shaft bottoms are usually fitted up very substantially, as they generally have a longer life than any landing or turnout in other parts of the mine.

1585. The empty and loaded tracks in landings, turnouts, and shaft bottoms have a slight fall in the direction the car travels, varying from about 0° 35′ (1 in 100) to 1° 10′ (1 in 50) depending on the size of rail, the size of car wheels, etc.

1586. When the shaft bottom has a frail top, or other conditions prevail which necessitate arching, the following plan is pursued:

The arches are built in lengths of from 6 feet to 10 feet, varying with the nature of the ground. The first operation in arching is to remove the material. This may be accomplished by driving a small road at the top of the ground to be excavated, and then removing the material from both sides and downwards; or by driving the small road at the base and removing the ground from the sides and upwards. In carrying up the temporary timbering, all the main sticks are set parallel to the road, so that they may be removed as the masonry is brought upwards. When props are used in the center of the excavation, the small end should be down, because when the masonry in the invert (floor arch) is built around them, other props are set on the masonry, and the old ones can be easily removed. If the large end is down, the props can not be conveniently removed.

1587. Figs. 491 and 492 show the method of timbering in two stages. In Fig. 491, *A* is a cross-section and *B* is a longitudinal section on the line *x y*, where the top head has been driven. Two long bars *a*, *a* are set with one end of each resting on the arch *g* and the others on the set of timbers *f*. They are connected by horizontal struts. The ground is first excavated on the sides, and longitudinal bars *c*, *c* are put in and connected by struts *d*, *d*, and lagging is placed behind them, if the ground requires it. Fig. 491 represents the work at this stage, the two longitudinal pieces *c*, *c* being supported by props *e*, *e* set on the floor.

As the excavation proceeds downwards, the props *e*, *e* are

removed as soon as space is made for other longitudinal pieces. This process goes on until a complete lining, consisting of longitudinal bars and cross-struts between them, exists all around the excavation. In heavy ground, the longitudinal pieces are often connected by transverse bars *a*, *a*, Fig. 492. Vertical props *b*, *b* are set between these bars until, at the completion of the work, the appearance is as shown in Fig. 492, where *A* is a cross-section and *B* a longitudinal section on the line *x y*. The masonry is now commenced. A lining of sand is spread in the bottom, and shaped to the curve of the brickwork. A wooden frame or "template," built the exact shape and size of the finished dimensions of the inside of the arch, is fixed at such a height above this sand as will allow the thickness of the brickwork decided upon to be placed between it and the sand. The bottom arch or invert is built first; then the sides are continued until they meet in the center line at the top of the arch.

1588. In most of the shaft bottoms in America, cars are caged from both sides, there being an empty and a loaded track on each side. It is often necessary to pass cars from one side to the other, and because the law (of Pennsylvania) requires a passage around the shaft, the bottom is so arranged. In well-arranged collieries, the caging is all done from one side, and the cars travel in the direction shown by arrows in Fig. 493, the tracks having a down grade in that direction.

Perhaps the most satisfactory arrangement of a shaft bottom, where conditions are favorable, is shown in Fig. 493, in which *P* is a plan and *K* a section of the roads. The method of handling the cars is as follows: A loaded car is taken from the road *a* to the shaft *s* by way of the road *d* or *e*, depending upon which cage is down, and by it the empty car standing on the cage is bumped off and run by gravity to the point *b*, and by virtue of its start it ascends the steep grade *b c* sufficiently far to give it force enough when it reverses to run along the road *b g d* far enough to accommodate a trip of cars. At the point *b*, there is a pair

of spring-latches allowing the car coming from the cage to pass through them, but always keeping adjusted for the road *b g d*. The grade from *a* to *s* is usually from 1 to 2 per cent..

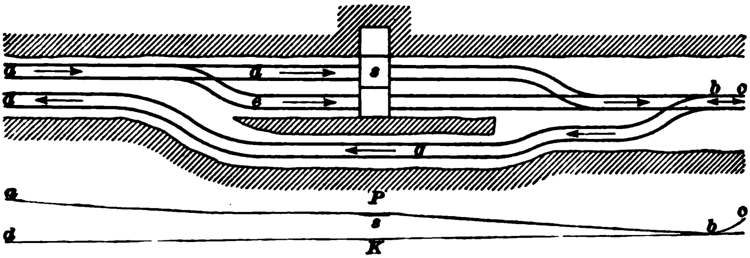


FIG. 493.

that from *s* to *b* is from 5 to 10 per cent., or more, depending upon the distance between these points, and that from *b* to *g* is about 2 per cent., beyond which point the road is made level for any desired distance. By this method men are required on that side only of the shaft on which the loaded cars are handled. The arrows indicate the direction in which the cars run.

1589. Fig. 494 shows a somewhat more complicated arrangement of a shaft bottom in which several pairs of headings branch away from the immediate vicinity of the shaft. In each pair of headings one heading is used for the loaded and the other for the empty cars. The loaded cars reach the shaft on one side only by the roads marked *l*, and, as in plan shown in Fig. 493, the loaded car bumps the empty car off the cage, causing it to run down the grade *s b* and thence up the grade *b c* to a point where it reverses and runs back, taking the road *f* or *e*, depending upon where the trip is being made up. If it takes the road *f*, it may be switched on to the road *g* or *h* or allowed to continue straight on, depending upon where the car is wanted. The arrows show the direction in which the cars run; *p* is a pump-heading, *r* a room heading, and *m* a manway around the shaft. The space *w* in the heading *k* is for stables, tool-house, etc. The grades are made so that the cars run to place by gravity.

1590. Where double or triple-decked cages are used, the arrangement of the shaft bottom is a more complicated

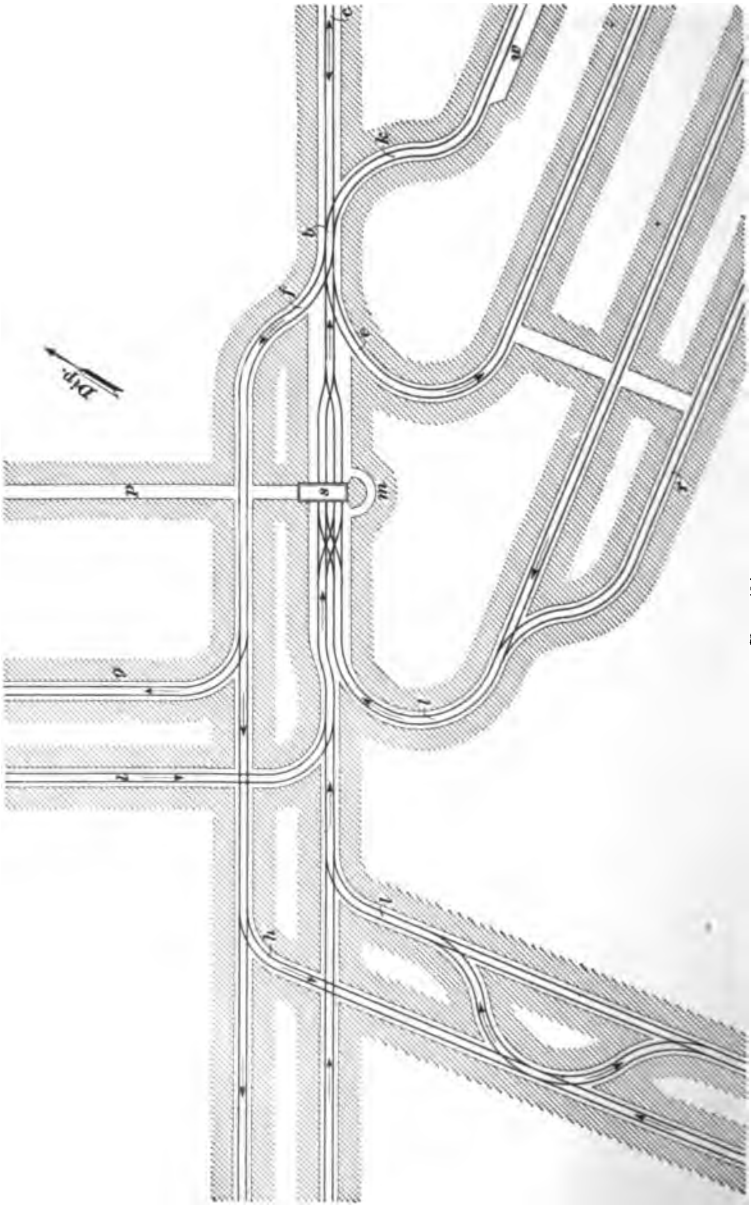


FIG. 404.

matter. By the arrangement shown in Figs. 493 and 494, the gradients are so arranged that the movement of the loaded and empty cars is almost automatic. When there is more than one deck, this arrangement will only suit when the position of the cage is changed to bring each deck alternately on a level with the shaft bottom. Each change will take nearly as much time as hoisting one car to the surface by a single cage. To overcome the difficulty of changing the position of the cage, the bottom is arranged to suit the decks of the cage, the loaded car being lowered to the deck-level and the empty cars being raised to the level of the seam by an inclined plane or an engine. When there is considerable dip to the seam, if the production from each side is equal, two decks may be used by making the bottoms independent of each other, at levels suiting the *decks* of the cage.

1591. Where endless chain or rope haulage is in use, the cars may be made to pass at will from one landing to the other by simply arranging the chains or ropes to suit the conditions.

PILLARS IN THE MAIN WORKINGS.

SIZE OF PILLARS.

1592. In determining the size of the pillars for the main workings, at least five points are considered:

1. *The Ventilation Required.*—If there is much firedamp or chokedamp given off, or much powder used, the formation of long pillars without cross-cuts necessitates a special and expensive mode of ventilating each working face by carrying a board or canvas brattice from the nearest cross-cut to the face. This enables air to be carried to the face along one side of the brattice, and returned along the other. In some cases where considerable good building material is obtained from the waste, packwalls a few yards wide and built close against the roof take the place of the brattices.

2. *The Nature of the Roof and Bottom.*—Where the roof, or bottom, or both are soft, large pillars and long narrow

openings are required. Frequently the top is supported by the pillars and props for a long time. The weight, which tends to crush the coal, and disintegration by atmospheric agencies, necessitate in such a case larger pillars.

3. *Depth of the Seam.*—To obtain better proportioned pillars, the best practice seem to indicate that the pillars should be not only larger, but the proportion of their widths to their lengths should increase as the depth increases.

4. *The Detailed Mode of Working Adopted.*—This has a very great influence on the size of the pillars.

5. *The Tonnage Required.*—As a general thing, short pillars are most favorable to the production of large outputs.

DIRECTION OF PILLARS.

1593. Speaking in a general way, pillars with their longest sides parallel to the pitch of the seam are the strongest and most suitable. However, it is very desirable to have the rooms, and, consequently, the pillars, running parallel to the "butt" cleats and perpendicular to the "face" cleats of the coal, thereby securing the better and cheaper coal. Sometimes, when the inclination is very great, it is found that the cost of hauling the coal is reduced by making the rooms and pillars run parallel with the strike of the seam. In cases where the course of the haulage road is diagonal to the course of the rooms, care must be taken in setting out the first range of pillars, so that those following may be of proper size. Errors due to neglect of this precaution are troublesome.

PROPORTION OF PILLAR TO OPENING.

1594. When an undue proportion of coal is mined in the first working, creeps are induced, with all the accompanying evils of crushed coal, the dilapidation of roadways and airways, the consumption of labor and material, and the suspension of the power of production, while additional expense is incurred in repairing the damages arising from such indiscretion. In fixing the proportion of pillars to openings, the following important points must be considered:

1. *The Nature of the Coal.*—Some seams are of such a nature that the sides and corners of pillars chip or split off when the coal is opened up, thus causing considerable waste. This splitting or chipping is due to the disintegrating effect of the atmosphere, or to pressure of gas in the coal, or to the pressure of the roof, or to any two of these causes combined, or to all three. When this chipping or splitting off of pillar coal occurs, pillars of greater area are required.

2. *Nature of Roof and Floor.*—If the floor is soft and the roof hard, small pillars are so squeezed down as to be both troublesome and expensive to remove, and the floor is very liable to "creep." If the floor is hard and the roof brittle, the latter will fall more or less in spite of all efforts, and the expense of "cleaning up" and timbering is heavy. If top and bottom are both strong, the weaker substance—the coal—is crushed, and its value proportionately decreased.

3. *Inclination.*—A very hard roof, such as a sandstone or limestone, will not break down in the ordinary working places, and so all the weight remains on the pillars until their removal begins. Then, although in pitching seams the amount of pressure varies inversely as the inclination, and is less than in flat seams, there is great danger of a rush or movement of the strata over the pillars, when robbing or withdrawal begins, unless they are large in proportion to the openings.

4. *Dislocations.*—These cut up the strata, and when of large size and running in certain directions, necessitate a greater proportion in pillars to withstand the pressure of the dislocated and subsequently loosened roof, when a subsidence is brought on by the removal of the pillars next them. If no attention is paid to dislocations, disastrous "crushes" may ensue, destroying acres of pillar coal.

5. *Depth.*—The depth of the seam is really the measure of the pressure. The aggregate power of resistance of the pillars must not merely sustain this pressure during the first working, but it must have such a surplus, and that so distributed, as to ensure the safe, economical, and entire

extraction of each pillar in turn. A depth may be finally reached when the pressure can not be resisted by pillars of any size, and the pillar method must be abandoned. The limit of depth varies with the nature of the coal, inclination, nature of strata, etc. In the foregoing, the conditions affecting the formation of pillars in the first working of the pillar method (often called working in the "whole") have been considered. It is now in order to treat of the second working, sometimes called the "brokens," which is the removal of the pillars. This requires the exercise of sound judgment and much good practical skill.

PILLAR DRAWING.

1595. Generally speaking, the sooner, consistent with economy, that the pillars are removed the better. In gaseous mines the pillars ought not to be taken out until the workings have reached a considerable distance from the shaft. If the coal is tender, the strength of the pillars should be considerable, and their removal delayed; because, if they are taken out, the probability is that those left for the support of the passages will be destroyed by the pressure, especially if the roof is good. In the case of bad roof, the pillars should be taken out as soon as possible, not only for economy, but also because, when the roof is bad and falls freely in the gobs, the débris soon sustains the superincumbent pressure and relieves the weight on the pillars next the hauling or main roads. Early drawing of pillars also concentrates the working district, and gives greater facilities for keeping up a limited extent of workings, and makes the ventilation more efficient and simple.

1596. In some cases the following conditions must be considered before pillar extraction is started :

1. *Working Contiguous Seams.*—When two or more contiguous seams are worked simultaneously, the removal of the lower pillars may very seriously affect not only the economy but the safety of the operation above. It may, therefore, be better policy to leave the pillars in the lower seam a much longer time than if there was but one seam.

2. *The Character of the Roof.*—If the roof is very strong and the area of pillar drawing is comparatively limited, a very dangerous amount of weight will be thrown on the remaining pillars; or, if the faces are not sufficiently far advanced, the disturbance produced in the strata may extend far enough to injure them.

3. *The Amount of Water that May be Let into the Workings by the Subsidence of the Roof.*—When a water-bearing stratum lies within the probable zone of subsidence, care must be taken not to disturb it.

4. *Surface Damages.*—In some cases, the immediate consequence of drawing the pillars will be the subsidence of the surface, which may result in large claims for damages.

1597. The conditions at collieries are so varied that no rule can be laid down to suit all. The effect of pressure varies with the nature of the roof and floor.

If the roof has fallen in the rooms, the drawing of a pillar can be most advantageously accomplished by taking a skip or slab off one side, advancing from the mouth of the room, and finally taking the remainder on the retreating plan. If, however, the roof is so strong that the entire extraction of a pillar is accomplished without inducing a fall, an enormous weight is thrown on the adjacent pillars. This has a tendency to crush the pillars if the floor is hard, or to force them into the bottom if it is soft.

1598. The order in which pillars are removed is important, as it affects both the safety and economy of the work. In working pillars on a pitch, a lower range should not be commenced till those immediately above are finished. In drawing pillars, their ends should be kept in a *straight* line. If they are not, some pillars are subjected to greater pressure than others, valuable coal is lost, and the work is materially interfered with. When all the pillars are left standing till the boundary is reached, the pillars are best drawn outwards.

1599. There are several ways of drawing pillars. When a pillar is small, it may be removed by one operation, but

when it is large, a skip or slice is often taken off its entire length and the remainder removed in the same manner as a small pillar.

In other cases, when the pillar is large, a narrow place is driven across or up the center, splitting the pillar in two, and then the two portions of coal left at the sides are brought back together. This is practised in some parts of the anthracite coal fields of Pennsylvania.

1600. Care must be taken to work out the coal without leaving small stumps, or portions of pillars, scattered through the gob, as they interfere with the uniform breaking of the top. When the surface must be kept up, and the pillars are large, skips or slices may be taken off them. This operation is termed **robbing** or **skipping** the pillars. When the pillars are entirely removed, the operation is termed **drawing the pillars.**

THRUST AND CREEP.

1601. Thrust and creep are both due to insufficient pillars. When the roof and floor are strong and unyielding, and the pillars are insufficient to withstand the pressure thrown upon them, they are filled with breaks and cracks, large pieces split off, and the pillars are finally crushed into small coal. The roof comes down, thrusting the coal out, and the result is known as a **thrust** or a **crush.** When the material composing the floor or roof, or both, is soft and weak, and the pillars left are too small, the weight upon them causes the roof to sag, or the floor to bulge, or both. This result is known as a **creep.** A thrust and a creep may both be going on at the same time.

1602. Stopping a Creep or a Thrust.—When any sign of a creep or a thrust appears, the pillars should be reenforced as much as possible by wooden chocks, or nogs, and by supports of any kind that can be put up just outside of the part affected. If the action of the creep or thrust is slow, sometimes the coal is extracted rapidly from some pillars, which will allow the top to break and thus relieve

the standing pillars of some of the weight. *A creep or thrust can not be prevented by any means when it has set in, but it may be confined to a limited area, if caught in time, by reenforcing the pillars as stated above.* The creeping or thrusting will go on until the excavations are filled, and the whole becomes compact enough to resist the weight. This sometimes takes many months, but it is a sure result, be the action fast or slow. Confining a creep or a thrust to a certain limit is a difficult, expensive, and dangerous operation, requiring the utmost skill and care in every individual engaged in the work.

1603. Reopening.—After the subsidence has entirely stopped, the pillars of coal subjected to thrust or creep may be partially recovered by methods adapted to the thickness of the seam. Thin seams can not be opened very readily, and, indeed, unless the coal is very valuable, reopening thin seams seldom pays. The old entries must be reopened by taking up the bottom, or taking down the top rock, which must be stowed in any open place, or taken to the surface, or by driving new entries across the pillars; in any case, much rock must be handled. In thicker seams, say over 6 feet, it is customary to make new roads by skipping the pillars; i. e., by taking a strip off the side of the pillars wide enough to carry a road under new top. In such cases, much timber must be used on the broken side, and where the road is carried across the waste or old excavations. Moreover, a district may again begin to creep or thrust whenever work is renewed on the pillars. In most of the cases tried, in many ways, and under many different circumstances, the operation was very unsatisfactory.

METHODS OF WORKING BITUMINOUS SEAMS.

1604. Fig. 495 shows seven districts worked on the "Pillar and Chamber," "Pillar and Stall," and "Panel" systems, principally in vogue in the bituminous coal fields of the United States. Several methods can frequently be combined to advantage in the same mine.

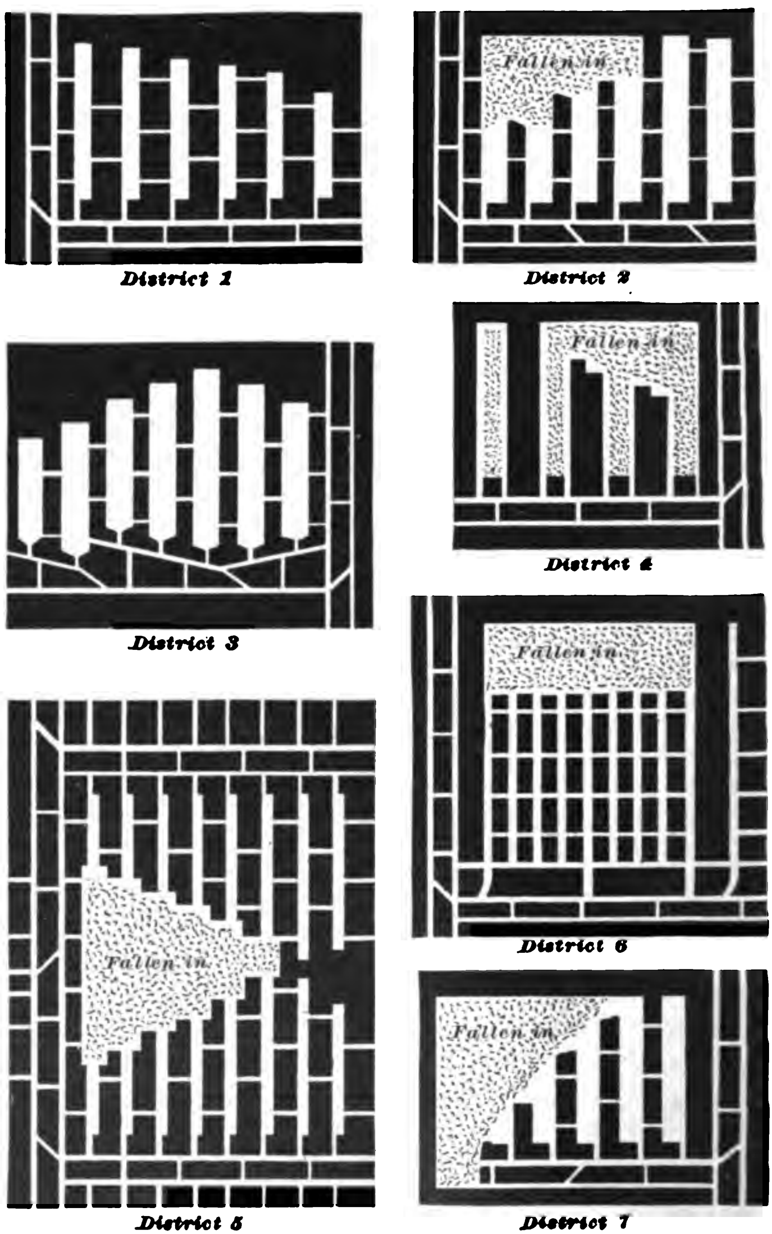

Fallen in
Fallen in
Fallen in
Fallen in
Fallen in
District 1
District 2
District 3
District 4
District 5
District 6
District 7

FIG. 495.

Most mines in the bituminous regions of the United States are opened up by the **double-entry system.** In this system, the main and butt, or productive, entries are driven in pairs and in definite directions suitable for the most economical and advantageous working of both the rooms and the pillars. The **triple-entry system,** which consists of a main entry or intake in the center and a return air-course on each side, is used either where the seam generates a large amount of gas, or for the purpose of getting out large quantities of coal, particularly when mined by several different systems.

1605. District 1 represents a group of "breasts," "rooms," or "chambers" which are driven about 6 yards wide and 12 yards apart. Narrow cross-cuts, called "break-throughs," are driven from room to room for ventilation. The heading from which the rooms are turned off is the haulage road, and the other heading is simply an airway. This system is used where the pillars are to be left in for the purpose of preventing any serious settlement of the surface, whereby buildings may be injured or water let into the mine.

1606. District 2 is a group of rooms showing the method generally used where the roof is good and the dip of the seam does not exceed 8 degrees. The rooms are about 8 yards wide and the pillars 6 yards wide. Where the dip is 3 degrees or more, the rooms are turned off to the rise only, the lower heading being used simply as an air-course. There is no road in the air-course, except near the face, the coal being taken out to the principal entry through diagonal cross-cuts at intervals of about 60 yards. When a new diagonal cross-cut is completed, the road is taken up in the one just back of it and is laid down in the one just finished. The rooms are turned off up the pitch, thereby avoiding any hard pull while taking the loaded cars from the face. When the seam pitches less than 3 degrees, butt headings are turned off the main headings, in pairs, at intervals of about 200 yards, and rooms are turned off both butt headings to the

right and left of each pair. This method, when it can be used, requires only one-half the number of butt entries required by District 2 to develop a mine. Also, when the butt entries are driven to the rise, the rooms are turned off to the right and left along the strike.

1607. District 3 shows a manner of grouping rooms where the dip is greater than that for which group 2 is used, and may be used on pitches from 8° to 20°.

The straight heading is driven on the strike of the seam, and the other headings at such angles to it as will give a good grade for haulage purposes.

1608. District 4 shows a group of rooms, each of which is 36 feet wide, with a pillar of the same width on either side. There are two entrances or "necks" to each room, and two roads, one along each side, the gob or refuse being thrown in the middle of the room among the props which support the roof. Sometimes, where it is advisable to work the coal by wide pillars and rooms, more particularly wide rooms, the rooms are turned off, as in District 2, and a road is carried up the center of the first room, the gob being thrown on either side, and in the second room, two roads are laid as in District 4, except that the roads connect just before passing through the neck of the room. This is carried on alternately to the end of the district, and the pillars are drawn in the double-road rooms only.

1609. District 5 shows a group of rooms suitable to work a seam of tender coal, having a soft top and bottom, and lying about 300 feet below the surface. Narrow 12-foot rooms are driven 40 feet apart, and the pillars are drawn back by taking say 16 feet off the roadside pillar and 12 feet off the gobside pillar.

1610. District 6 shows a group of nine narrow rooms driven to the rise for 300 feet, and the pillars drawn back together. Between each section of nine rooms extra large pillars are left to break the rock in case of a fall, and prevent a squeeze on the adjoining section which may not have reached its limit.

In some cases, still narrower rooms are driven along the strike of the seam, in pairs; and between each pair, pillars 20 yards wide are left. Which method to adopt is determined by the nature of the coal, especially with regard to the relative prominence of its face and butt cleats. The method shown in District 6 is preferable where the cleats are equally prominent in face and butt; while in the case of a long-grained, tough coal, it would be best to work it by dividing the coal by pairs of rooms having wide pillars between each pair, as above described.

1611. This method of first driving narrow places say from 8 to 12 feet wide, and then drawing back the pillars, is termed **pillar and stall.** It will be observed that each group of rooms is surrounded by a large pillar in order that pillar drawing can commence in each group as soon as it reaches its limit. This gives us a system which will be explained next.

1612. District 7 shows a section of a mine worked on what is called the **panel system.** This system is a modification of the pillar and breast plan of working, by means of which a larger portion of the pillar coal can be obtained. It is not applicable to very thick seams, nor can it be successfully employed in steep-pitching seams. Where this system is used exclusively, the mine is laid off in "districts" or "panels," two or three acres in extent, and large pillars are left surrounding the area being worked within each panel. When the rooms of one panel are exhausted, the work of drawing the pillars is begun at the extreme end of the panel; and when this work is finished, all parts which may yet be standing are withdrawn so that the roof will firmly settle before the pillars in an adjoining panel are worked.

By the panel system, "creeps" are almost entirely prevented, the pillar or less expensive coal is gotten earlier, and good ventilation is secured, for each panel has its separate "split," or air-current. It is further maintained that, in case of an explosion, the damage may be confined to a particular panel in which it occurs. Any method may be

employed in developing the panel; in this particular case, the pillar and chamber method is used.

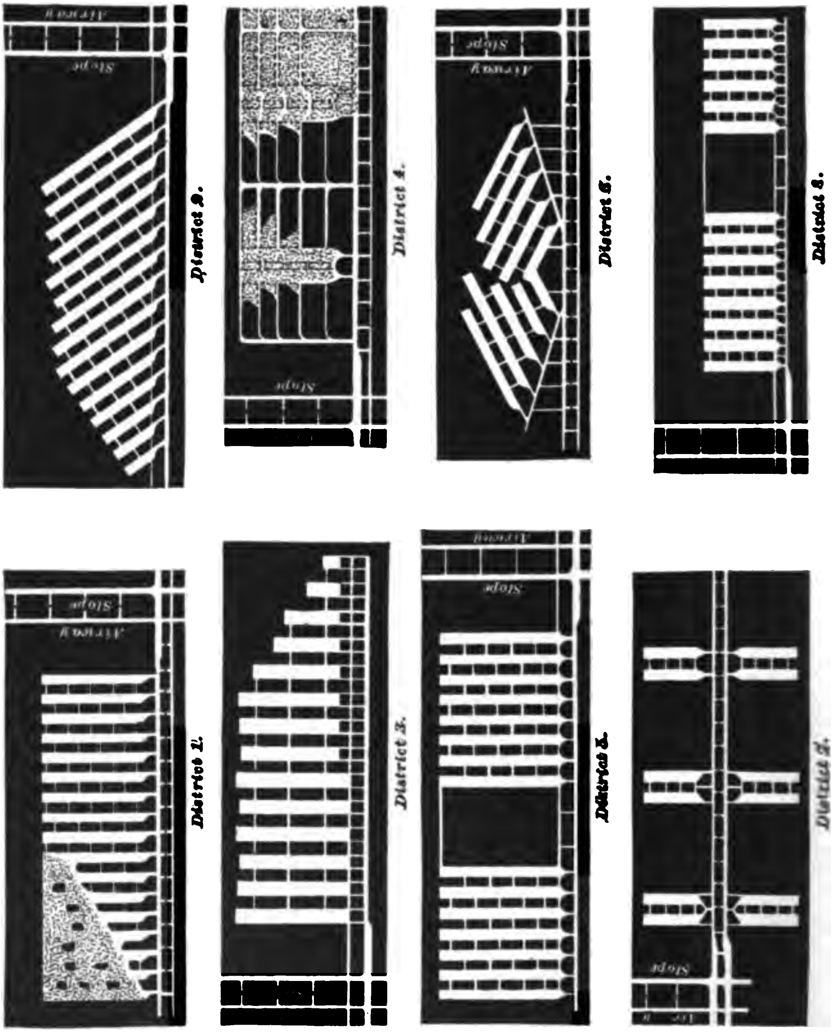


FIG. 408.

1613. It should be remembered that in all these districts the rooms are driven on the "faces," i. e.,

perpendicular to the face cleats, or as nearly so as possible, because more lump coal can be produced and the bearing in can be more easily effected than by driving them in any other direction.

There are conditions which require that the rooms should be driven at different angles to the face cleats; but these will be fully explained further on and need not be dwelt upon here.

METHODS OF WORKING ANTHRACITE SEAMS.

1614. Fig. 496 represents five different districts of mines in the anthracite coal region of Pennsylvania. These districts show in a general way the arrangement of the necks of the breasts for chutes best suited for particular pitches. This arrangement of the chutes, etc., will be explained in detail further on.

1615. In districts 1 and 2 the seam is nearly flat, and the coal is obtained in chambers varying in width from 20 to 30 feet. The coal is nearly all shot out of the solid, and a great deal is unavoidably lost in drawing back the pillars, the best results in thin seams being scarcely 80 per cent. mined. In district 1 part of the pillars are drawn, while in district 2 the rooms are not yet finished, and are driven obliquely to the level to obtain a moderate grade for haulage. A chain pillar which is parallel to the gangway and air-course is left between the different lifts, as the districts are called when on a pitch. Each of these pillars protects the lift immediately below it and prevents the water from running down into the lower lifts. Part of the chain pillar may be taken out when the lift just below it has reached its limit.

1616. The coal is supposed to have considerable pitch in districts 3 and 4. In district 3 the breasts are opened with two chutes each, and the rooms are 10 to 12 yards wide. In case there is a bottom split of the seam, one split should

be worked vertically above the other; that is, breast should be over breast and pillar over pillar. Sometimes an extra stump or small pillar is left immediately above the first heading or airway as an additional protection for the chutes and airway. In district 4 is shown a panel system devised by Col. D. P. Brown of Lost Creek, Pa., which gives good results in thick seams pitching from 15° to 45°, where the top is brittle, the coal free, and the mine gaseous.

In this plan of working, rooms or breasts are turned off the gangway in pairs at intervals of about 60 yards, as shown in district 4. The breasts are about 8 yards wide, and have a pillar between them about 5 yards wide, which is drawn back as soon as the breasts reach the airway near the level above. In the middle of each large pillar between the several pairs of breasts, chutes about 4 yards wide are driven from the gangway up to the airway above. They are provided with a traveling way on one side, giving the miners free access to the workings. Small headings are driven in the bottom bench of coal, at right angles to these chutes, and about 10 or 20 yards apart. These headings are continued on either side of the chutes until they intersect the breasts. When the chute and headings are finished, the work of getting the coal in the panel is begun by going to the end of the uppermost heading and widening it out on the rise side until the airway above is reached and a working face oblique to the heading is formed. This face is then drawn back to the chute in the middle of the panel. After the working face in the uppermost section has been drawn back some 10 or 12 yards, work in the next section below is begun, and so on down to the gangway, working the various sections in the descending order. Both sides of the pillar are worked similarly and at the same time towards the chute.

Small cars, or buggies, are used to convey the coal from the working faces along the headings to the chute where it is run down to the gangway below and loaded into the regular mine-cars. This system affords a great degree of safety to the workmen, because whenever any signs of a fall of roof

or coal occur, the men can reach the heading in a very few seconds and be perfectly safe.

It will be noticed that a great deal of narrow work must be done before any great quantity of coal can be produced by this system. The only reason that breasts are driven in pairs and at intervals, as above stated, is to provide means of getting a fair quantity of coal while the narrow work is being done; they are not an essential part of Col. Brown's system. It is claimed that the facility and cheapness with which the coal can be mined, handled, and cleaned in the mine more than counterbalances the extra expense for the narrow work.

1617. In districts 5 and 6 the seam is supposed to have a light pitch. In district 5 is shown a method of opening breasts with a single chute, in the center of which the coal slides on sheet iron. The breasts are worked from 8 to 12 yards wide and in groups of from 8 to 10 breasts. These groups are separated by strong pillars from 150 to 200 feet wide. These pillars are left in to prevent any very heavy crush affecting the gangway and working breasts, and to ensure the breaking of the top rock so as to relieve the pillars of excessive weight. In district 6 the seam is supposed to dip from 10° to 15°. This is not enough dip for chutes and too much for haulage roads on the full rise. Therefore, slant gangways or branch entries are driven off the main entry, and backswitch breasts are turned off them.

1618. In district 7 the gangway is supposed to be driven in the syncline or basin, and rooms are turned off to the right and left. Whichever system of opening the breasts is employed, the best results will be secured by carrying on the work in sections, or panels, having extra strong pillars of coal to support the overlying strata and as far as possible to lessen the crush, which is considerable under such conditions and at so great a depth. In district 8 the pitch is very heavy. Under such conditions it is advisable

to work the coal in groups of eight or ten breasts each, as in district 5. The breasts are opened with a single chute and a manway, as shown. When the manway is driven as shown on the extreme right of district 8, it can be used as a chute, if necessary. Breasts with two chutes, similar to those in district 3, are also frequently opened up on very heavy pitches.

1619. In some cases it is advantageous to first drive the gangways to the limit before any of the breasts are opened, and to mine out the lift in sections, commencing at the inside end and robbing back the pillars.

1620. When a lift is greater than say 400 feet, a counter gangway parallel to the main gangway is driven from one of the rooms, from 250 to 300 feet on the pitch, above the main gangway, and rooms are opened from it. One of the old rooms is used as a chute to convey the coal to the lower gangway; and to avoid breakage, it is kept as full of coal as possible, or, if the inclination will permit, a self-acting incline is constructed in one of the rooms from the main gangway, down which the coal is lowered in the cars. Counter gangways are also sometimes made necessary by extensive rolls in the coal seam or by sudden and radical changes in the inclination of the seam.

METHODS OF OPENING AND WORKING BREASTS, CHAMBERS, OR ROOMS.

1621. There is considerable difference in the methods of opening rooms in anthracite and bituminous seams, owing to the differences in the physical characteristics of the seams, and the fact that anthracite coal will slide on chutes of less inclination than bituminous coal.

1622. In moderately thick coal seams pitching more than 4 degrees, and not more than 18 degrees, the rooms are usually driven across the pitch, thus securing a grade of track low enough to make easy the haulage of mine cars to the working face. When the pitch does not exceed 4 degrees, the rooms are turned off the gangway or level at right angles.

1623. There are two methods of mining the thick coal in breasts, when nearly flat :

1. The breasts are opened out and driven to the limit in the lower bench of coal, and the top benches are blown down afterwards, beginning at the face and working back.

2. When the roof is good and there is no danger of its falling and closing up the workings, the upper benches may be worked in the opposite direction, beginning at the gangway and driving towards the limit of the lift. When the seam is less than 12 feet, the top is supported by props; in thicker seams the expense is so great for propping that but little attempt is made to support the roof. In the thicker anthracite seams (notably the Mammoth) the coal in the breasts is so worked as to make an arch of the upper benches of coal, which acts as a temporary support for the roof, the coal in the arch being extracted when the pillars are robbed.

1624. Marked changes of dip may be so frequent that in a distance of from 300 to 600 feet nearly all the different modes of working breasts may be used. A breast may start on a very low pitch and the seam commence rising a few yards in, and the pitch may increase more and more until it becomes vertical. Or the reverse may be the case. The breast may start on a heavy pitch and gradually, or suddenly, become so flat as to necessitate the use of buggies, or small cars, to convey the coal from the face to the top of the pitch, down which the coal will slide in a chute.

1625. Fig. 497 shows a plan *A* and section *B* of a breast where the pitch becomes too steep for the mule to take the car up, and not steep enough for the coal to run or slide on sheet-iron chutes to the gangway. In the plan *A*, the roof is supposed to be removed from the coal and the reader looking down upon the bottom of the breast. The section *B* is laid along the line *b d*, and the reader is supposed to be looking towards the track in the breast. The coal is loaded into a small car or buggy *c*, and run down to the end of the tipple and delivered on a landing *l*, from

which it is loaded into the regular mine car. The refuse from the seam is used in building up the track, keeping it nearly level. When there is not sufficient refuse for this

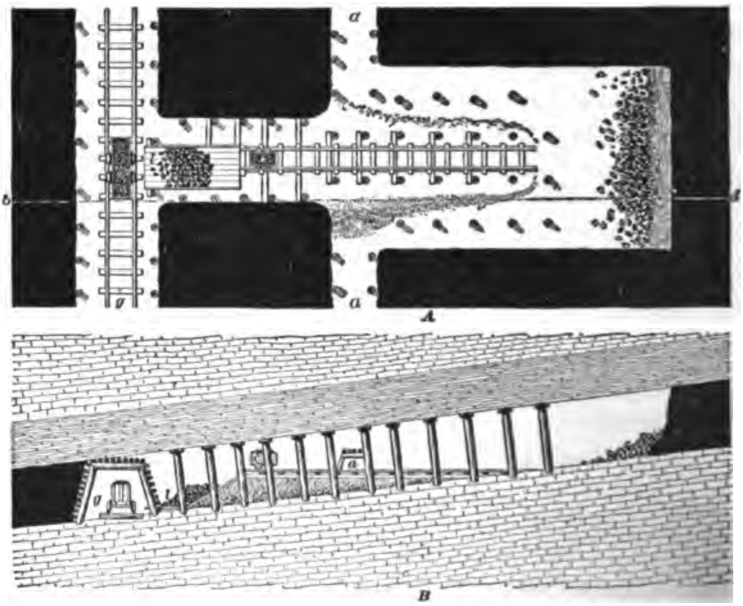


FIG. 497.

purpose, a timber trestle is used. The breast is turned off the heading *a* the full width and connected to the main gangway *g* by a narrow passage, as shown in the figure. This method is used in seams pitching between 10° and 18°.

1626. When the pitch of anthracite seams is from 15° to 30°, sheet iron is laid on the floor of the breast, and also in the loading chute, to facilitate the movement of the coal, but on pitches of less than 18° or 20° the coal will not move freely, and must be pushed down by the miner. When the pitch is greater than 30°, the coal will slide down without sheet iron.

1627. When the inclination of anthracite seams is less than 30°, the breasts may be opened with one chute in the

center, which ends in a platform projecting into the gangway, off which the coal can be readily loaded into the mine car. When this method is employed, the refuse is thrown to either side of the chute. If the pillars are to be robbed by skipping or slabbing one rib only, it is well to keep most of the refuse on one side. Sometimes, when the top is good, and the breasts are driven wide, two chutes are used, but the cost of making the second chute is considerable and is, therefore, not advisable unless necessitated by the method of ventilation employed.

1628. Fig. 498. In the plan *A* the roof is supposed to be removed from the coal and the reader looking down upon the breast. The section *B* is laid along the lines *h c* and *d b*.

The figure shows a method of opening a breast by two chutes *c*, *c*, when there is a great amount of refuse, or when a great amount of gas is given off. The chutes are extended, as the figure shows, up along the rib to within a few

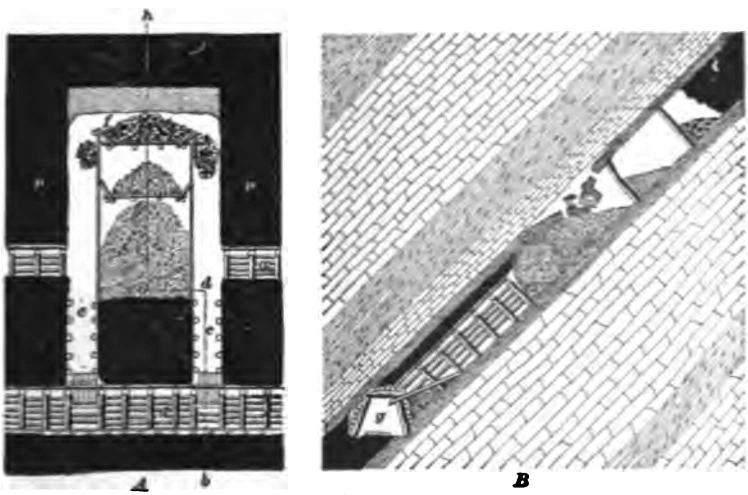


FIG. 498.

feet of the working face, either by planking carried on upright posts, or by building a jugular manway, so named because it is built of **jugulars** or inclined props, faced by

2-inch plank. It is made as nearly air-tight as possible, to carry the air from the heading *a* to the working face.

1629. The figure also shows a breast opened by this plan on a pitch too steep to enable the miner to keep up to the face. In seams of less than 35°, the platform *f* shown near the face of the breast is unnecessary, and in seams thicker than 12 feet it can not be built; hence, this method of working is applicable (1) to beds pitching more than 35°, and (2) to thin seams on heavy pitches.

The coal is separated from the refuse on the platform *f* and sent down the manway chutes, and the refuse is thrown in the middle of the breast behind the platform. A certain amount of coal is kept on the platform to deaden the blow from the falling coal.

The coal is run down the manway chutes and is loaded into the cars from a platform projecting into the gangway *g*. The chutes are timbered, but timbering is not erected unless the character of the coal requires it.

This plan can be employed in thick seams having a heavy dip, if there is enough refuse to fill the center of the breast so that the miner can work without the platform. The whole method is named **working on battery.**

1630. Fig. 499 is a section through *p p*, when jugulars *a*, *a* are used to form the manways *b*, *b* along the sides of

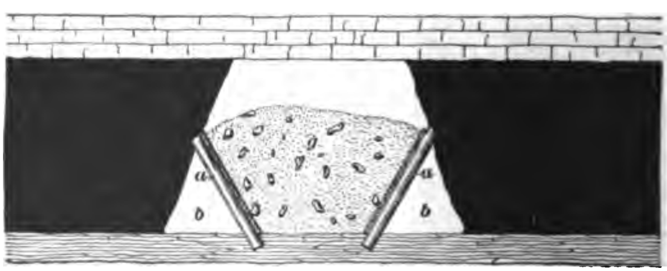


FIG. 499.

the breast, and Fig. 500 is a section through the same line when upright posts *a*, *a* are used to support the plank in

forming the manways *b*, *b*. The refuse *g*, in these cases, only partially fills the gob.

1631. In working very thick seams on heavy dips, where there is not enough refuse to fill the middle of the breast, the miner has nothing to stand on, the platform

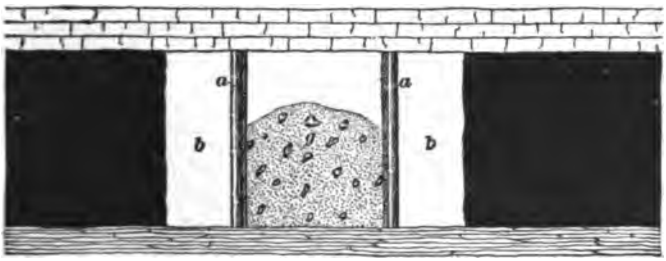


FIG. 500.

being impracticable; therefore, it is necessary to leave the loose coal in the breast, which involves the use of an entirely different mode of opening. Loose coal occupies from 50% to 90% more space than coal in the solid; therefore, when the coal is left in the middle of the breast, means must be supplied to draw off the surplus.

This surplus may be drawn out through a central chute with best results, because the movement takes place principally in the coal lying near the center of the breast. If the roof is poor, the movement of the coal will not in this way cause it to fall and mix with the coal; and, if the floor is soft, the jugulars, which are stepped into the floor, are not so liable to be unseated, closing the manway and blocking the ventilation. The surplus is sometimes sent down the manways, leaving the loose coal in the center of the breast undisturbed until the limit is reached.

1632. To prevent the coal from running out through the chutes, the opening into the breast is closed by a battery constructed by laying three, four, or five heavy logs across the openings, as shown at *b*, Fig. 501, or built on props as shown at *b*, Fig. 502; a hole is left in the center, or at one side of the battery, through which the coal may be drawn. The battery closes all of the openings into the

breast, except the space occupied by the jugular manways, and is made air-tight, or as nearly so as possible, by a covering of plank.

1633. Fig. 501 is a plan and section of a breast opened

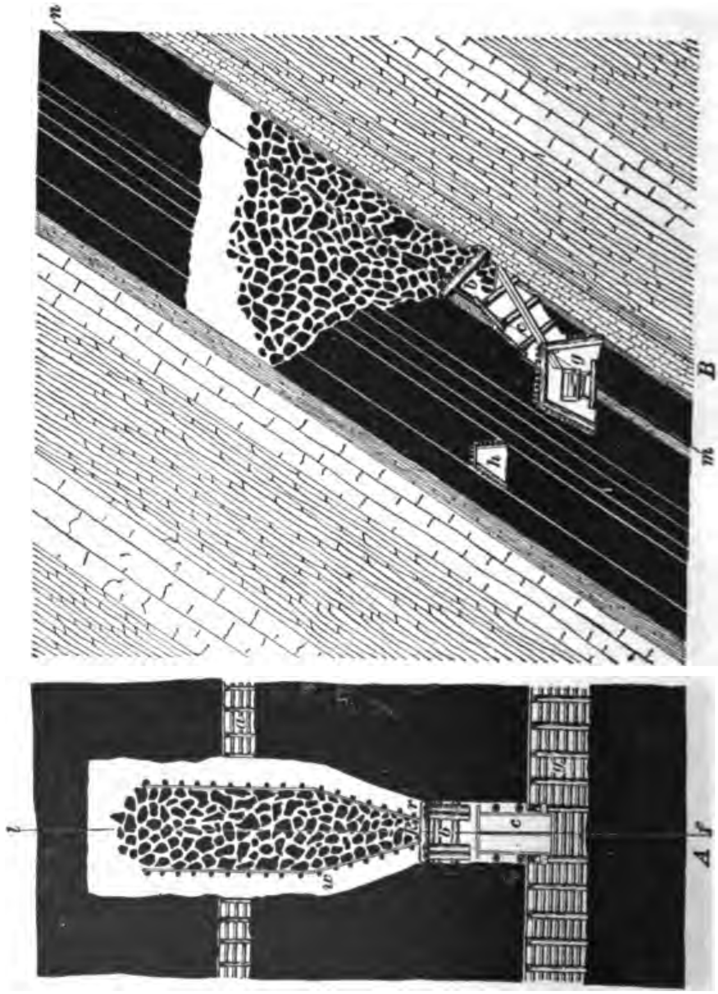


FIG. 501.

up by a single chute. The plan *A* is taken on the line *m n* shown on the section *B*, which section is taken on the line *f l* shown on the plan *A*. The pitch is great and the seam

is so thick that the breast must be kept full of loose coal for the men to work upon, the surplus being drawn off at the battery *b* and run into the car standing on the gangway *g* through the chute *c*. A manway *w* is made along each side of the breast, for the purpose of ventilation and affording a passage for the men to reach the working face. The heading *a* is used for an aircourse between breasts. The main airway *h* is driven over the gangway *g*, where it will be well protected.

By drawing the surplus coal through a central chute, the manways are not injured so much as when it is drawn off through side chutes, as the coal will move principally along the middle of the breast. When the breast is worked up to its limit, all the loose coal is run out of the breast and the drawing back of the pillars is commenced, unless for some purpose they are allowed to stand for a time.

1634. Fig. 502 shows a plan *A* and section *B* of double-chute breasts used in very thick seams having a heavy dip. The section *B* is made along the line *p q* on the plan *A*, and the plan *A* is made along the lines *r s* and *s t* on the section *B*. The breasts are entered by two main coal chutes *c*, *c*, each of which is provided with a battery *b*, through which the coal is drawn. A manway chute *m* is driven up through the middle of the pillar for a few yards, and is then branched in both directions until each branch (slant chute) intersects the foot of a breast near the battery *b*, as shown in the figure. The jugular manways *n*, *n* are started at this point and continued up each side of the breast. The main airway *h* is driven in the solid, through the stump *A* above the gangway.

1635. The figure also shows the main gangway *g* driven against the roof. By driving the main gangway against the roof, where the pitch is heavy, the loading chute *c* is more readily controlled, because the pitch of the chute is lessened.

When the main gangway is not driven against the roof, a gate is placed in the chute below the check-battery, which

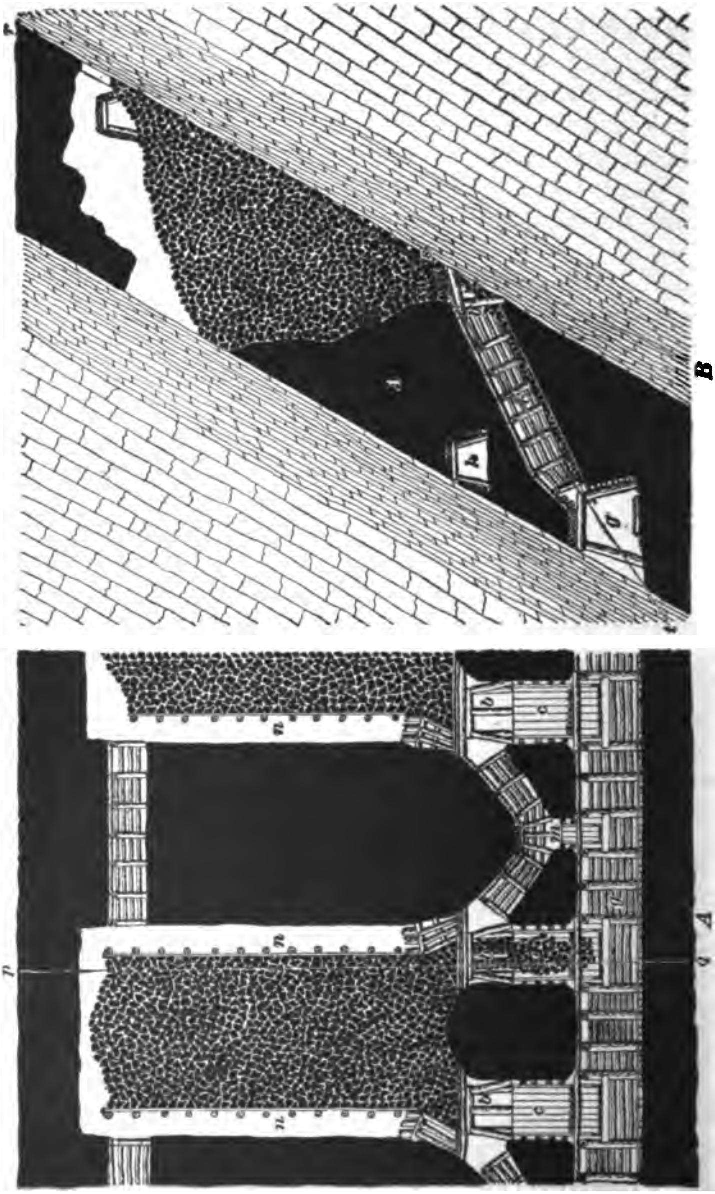


FIG. 503.

enables the loader to properly handle the coal. Coal in excess of the amount necessary to keep the miner up to the face may be drawn through the main battery, or sent down the manway chute, from which it is loaded through an air-tight check battery.

The main chutes are usually 8 or 9 feet wide, but sometimes only for the first 6 or 8 feet; above this they are driven about 6 feet square. The manway and *slant chutes* are also about 6 feet square.

1636. When the seam is not thick enough to carry the return airway *h*, Fig. 502, over the gangway, the chutes are driven up in the same manner as in Fig. 502, for a distance of about 30 feet, where they intersect the airway. The breast is opened out just above the airway, a battery being built in the airway immediately above each chute. A manway is driven from the gangway up through the middle of the stump until it intersects the airway, and a *trap-door* is placed at this point to confine the air. This manway is made about 4′ × 6′, or smaller.

1637. Fig. 503 shows a less complicated plan than Fig. 502. In this plan the main chutes *n*, *n*, are driven up to the heading *c*, from which the breast is opened out; a log battery is built at the top of each chute at the points marked *a a*. The chutes are used for drawing the battery coal, and for receiving the manway coal, and are also used for traveling ways.

In this case, and in the preceding cases, a check battery *b* is placed in the chute to prevent the air-current from taking a short cut from the gangway through the chute to the breast airways. This check battery is of great assistance to the loader when the chute has a very steep pitch, as he can readily control the flow of coal through the draw-hole.

1638. All of these methods are open to the objection that in case of any accident to the breast manway, by which the flow of air, shown by the arrows, is obstructed, there is no means of isolating the breast in which the accident occurs, and the ventilation of all the breasts beyond it is entirely stopped.

To overcome this, sometimes the pillar A, shown in left-

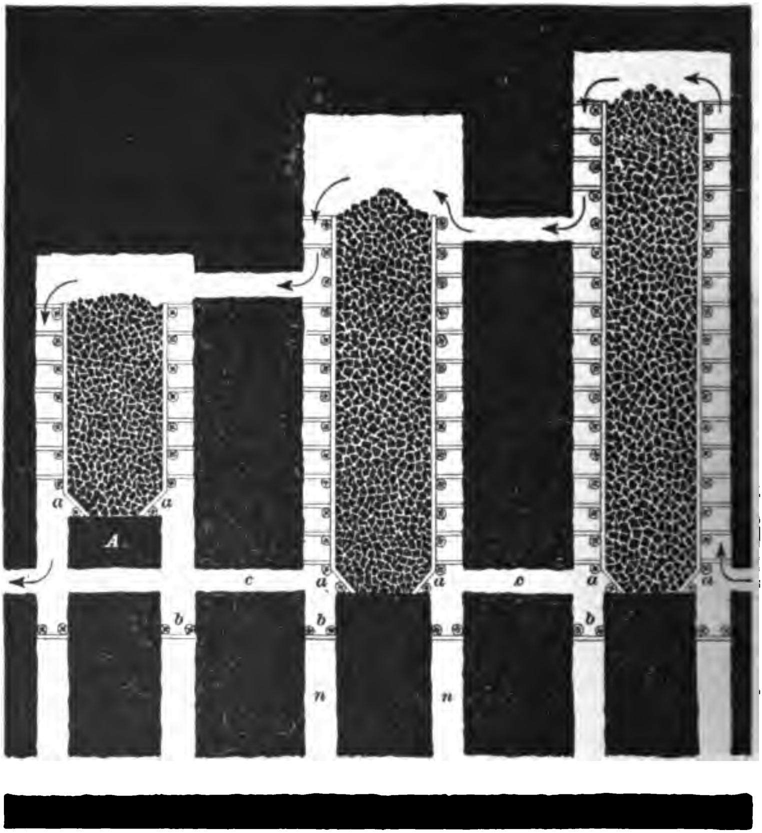


FIG. 503.

hand breast, Fig. 503, is left in each breast to protect the airway.

1639. Fig. 504 shows a plan A and section B of a breast worked in a seam sufficiently thick to have the airway c driven over the gangway g. The breasts are open by a chute 9′ × 6′, driven up the pitch; or, if the gangway is driven along the top rock, in thick seams, the breast is opened by a chute driven across the seams a distance depending on the dip, but usually from 24 to 36 feet; the breast is then

gradually widened out to the proper width on both sides, as shown in the figure. The section is made on the lines *l k* and *i j*, and the plan is made through the lines *p q*, and therefore does not show the headings *c* and *d*. In the middle of each stump a small manway chute *m* is driven up a few yards, and then branches *s*, *s* are turned off in both directions until intersection is made with each breast. From the top of these manway-chutes, manways *w*, *w* are carried up on each side of the breast, as in other plans. It will be

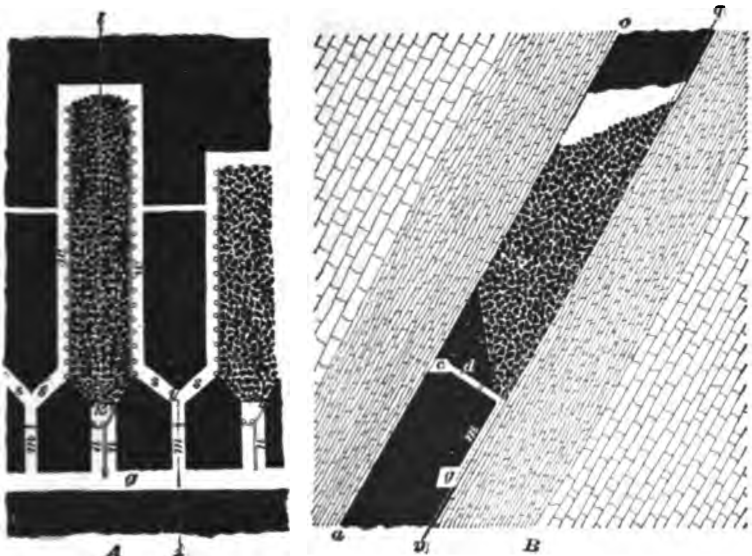


FIG. 504.

noticed in this case that the main chute *a* and battery have no connection with the slant and manway chutes *m*.

A narrow manway *n* is usually made by planking off a portion of the main chute so that the loader may have free access to the battery at all times.

When the pitch exceeds 50°, the gangway is sometimes driven in the top bench of the coal, which lessens the risk from a squeeze, and the chutes may be driven at an angle on which the coal will be most easily controlled.

This plan, however, is not frequently adopted, because it

incurs an extra cost in opening up the breasts by having to drive the chutes much further than is necessary when the gangway is driven along the bottom of the seam.

A small airway *d* is driven from the airway *c* to the manway chute *m*, but cross-cuts between the airway and gangway are also necessary where the headings are long and give off much gas while being driven.

The small airway *d* and the airway *c* are not used when the breast is working, but if any accident takes place in a breast manway by which the ventilation is blocked, the air can be conveyed around the breast through the airways *d* and *c* by simply removing the stoppings.

This plan is especially adapted to working thick, steep-pitching seams of soft, gaseous coal.

In many seams the gangways, levels, or entries are driven to the boundary before any pillars or stumps are drawn; and, in order to prevent a squeeze overrunning the stumps and pillars when they are being drawn, a strong pillar or block of coal 150 to 200 feet along the gangway and of the same length as the rooms is left at regular intervals of about 600 feet, a range of breasts being driven between the pillars thus left.

1640. Fig. 505 is a sectional view of a thick seam of coal standing vertically and mined by breast and pillar.

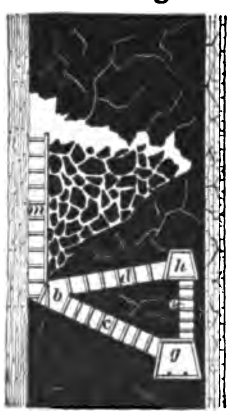


FIG. 505.

The lower part shows the arrangement of the gangway or level *g*, airway *h*, and chute *c*. The battery *b* is at the inner end of the chute and near the foot of the vertical manway *m*. The passages *d* and *e* are for the purpose of ventilation and affording easy access to the battery at the foot of the vertical manway.

1641. Fig. 506 is a profile of what is called a "back breast" *p* in the thick anthracite seams. The regular breast *b* having been mined out and probably abandoned, the coal over the main gangway *g* and monkey or air gangway *k* is worked by opening

a breast *p* off the monkey or other gangway driven in the coal, so that the coal may slide through chutes to the cars.

FIG. 506.

Such a mode of working may enable a large proportion of the gangway stumps to be removed, which otherwise would be entirely lost.

1642. Fig. 507 is intended to give some idea of the methods adopted in robbing or extracting pillars in steep-pitching thick beds of anthracite. It shows three worked-out breasts, *A*, *B*, and *C*, and the greater part of four pillars, with the bottom of a chain pillar just showing along the top of the cut. In *A* and *C* the manways remain, but they are supposed to be destroyed or removed in *B*. In order to get the coal out of the pillar on the left of *A*, the miner takes a "skip" off the side, and the figure shows a shot just fired and the coal falling down the old half-empty breast. This skip having been worked off, another is taken, and so on, as far as is safe or necessary until the pillar is gone, the miner retreating downwards as the work goes on, always keeping a manway open as a safe means of retreat to the heading

below. The pillar separating A and B will be worked away much in the same way. The pillar between B and C is shown as being taken out in a different way. A narrow chute or heading is driven right up the middle of it and cross-cuts put in right and left a few yards from the upper end. Into the middle of each square block of solid coal so formed, shots are put in as indicated by the white lines, and all fired

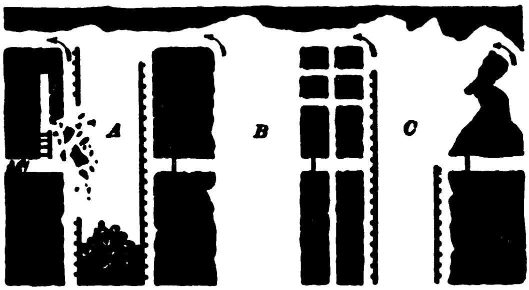


FIG. 507.

simultaneously by a battery. The operation is repeated in each descending portion of the pillar, unless, as sometimes happens (especially in very jointy or free seams), the pillar starts to run, which even a breast will often do under favorable conditions, so that scarcely any *mining* need be done after the gangways are driven, and the chutes started, and "batteries" formed. A case of the coal running of its own accord is sketched on the right of C.

ROCK-CHUTE AND TUNNEL MINING.

1643. Fig. 508 shows a section of two seams, separated by a few yards of rock, and worked on what is known as **rock-chute mining.** Chutes, from 4½ to 7 feet high and 7 to 12 feet wide, are driven in the rock from the gangway or level g to the level l in the seam above, at such an angle that the coal will gravitate from the upper seam into the gangway g driven in the lower seam. The working, otherwise, is similar to that previously described.

1644. Vol. AC of the Geological Survey of Pennsylvania says *rock-chute mining* contemplates a sequence of operation which may be summarized thus:

1. The opening of all gangways and airways in the lower seam, to develop coal as yet untouched, in a thick seam lying a few feet above it.

2. Developing the thick bed by a regular series of *rock chutes* driven from the gangway below; workings being opened out from chutes as in ordinary pillar and breast working—the panel system or some other plan may be found better than pillar and breast workings.

3. Driving the breasts to the limit of the lift and robbing

FIG. 508.

out the pillars from a group of breasts as soon as possible, even if a localized crush is induced.

4. After one group of breasts is taken out and the roof has settled, opening a second series of chutes for the recovery of coal from any large pillars that were not taken out when the crush closed the workings.

5. While the work of recoveringthe pillar coal is in progress, a second group of breasts may be worked, and the process continued until all the area to be worked from that gangway has been exhausted. The same process is employed in opening lower lifts.

6. When all the upper bed of coal has been exhausted, the lower seam may be worked by the ordinary method. Workings in this seam may be carried on simultaneously with the upper bed, but to avoid the possibility of a squeeze destroying these workings, very large pillars must be left. After exhausting the upper seam, these pillars may be advantageously worked by opening one or two breasts in the center of each, and when these are worked to the upper limit, attacking the thin rib on each side, commencing at the top and drawing back.

When the roof of the lower bed is good, the cost of timbering and keeping open the gangways and airways will be considerably less than if these were driven in the upper seam, and this difference, in some cases, may be sufficient to pay for driving all the rock chutes.

1645. There are three undetermined points in this connection, viz.: 1. The maximum distance between the two beds, or the length of rock chute that can be driven with satisfactory financial results. 2. The maximum dip on which such working can be successfully opened. 3. The maximum thickness of the upper and also of the lower seam, which will yield results warranting the additional outlay when the rock chutes are of considerable length.

1646. Fig. 509 shows how one or more seams are worked by connecting them by a "stone drift," or "tunnel," driven horizontally across the measures, through which the coal from the adjacent seams is taken to the haulage way leading to the landing at the foot of the slope or shaft. Tunnels are sometimes driven horizontally through the measures from the surface, so as to cut one or more seams above water level.

The lower seam of coal is worked from a gangway or level *l*, connected by a "tunnel," or "stone drift" *t*, to the level or gangway *g*, in the thick seam. The "stone drift" may be extended right and left to open seams above and below the thick seam. This "tunnel," or "stone drift," is never driven under a breast in the upper seam, but directly under the middle of the pillar.

In the upper and thicker seam, when the coal is very hard, a breast *b* is worked to the limit and the loose coal nearly all run out through the chute *s* into the gangway *g*. The "monkey gangway" *m* is driven near the top as a return airway, and is connected to the upper end of the

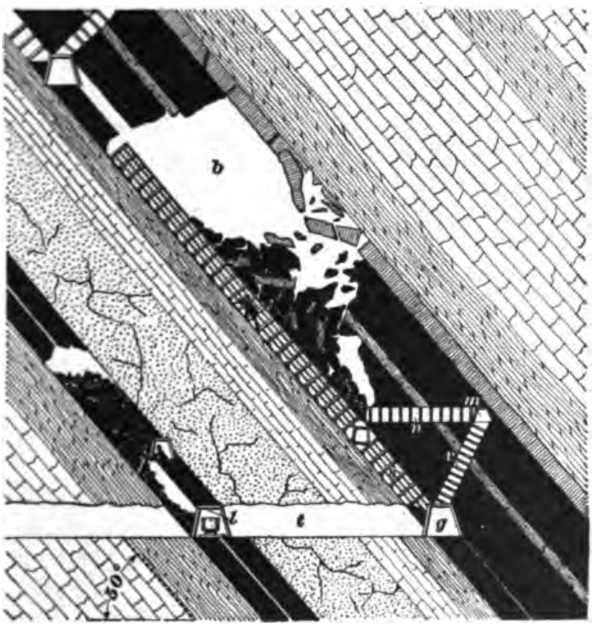


FIG. 509.

chute *s* by a level heading *n*, and to the main gangway *g* by a heading *v*. These headings are driven for the purpose of ventilation and to provide access to the battery in case the chute *s* should be closed. In the lower seam the breast is still being worked upwards in the ordinary manner.

WORKING CONTIGUOUS SEAMS.

1647. Fig. 510 shows the method of working twin seams separated by a few feet of slate or rock. This probably suggested the rock-chute method shown in Fig. 508.

To the right of the figure, the seams are quite flat and are worked by running the car *c* from the level *l* into the

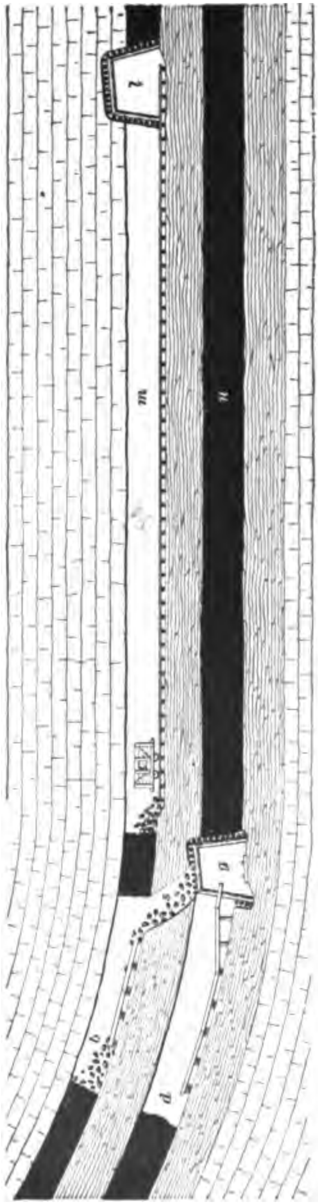


FIG. 510.

breasts; while to the left of the figure the seams begin to pitch rapidly and the breasts are worked by chutes, and one vertically over the other. The coal in the breast *b* is conveyed to the gangway *g* by means of a rock chute *s*, necessitating but one gangway for both seams. The breast *d* is shown with all the loose coal run out in cars on the gangway and taken away.

1648. Twin seams are usually worked together until the parting becomes 4 feet or more in thickness, after which it is best to work them separately.

Split seams, or seams lying close together, are mined by first working the lower seam to the limit and then dropping the parting and mining the upper seam outwards. In some of the flatter seams the upper seam is mined by dropping the parting and taking down the upper coal, keeping its face a short distance behind that of the lower seam.

1649. When there are several seams to be worked in the same field by the pillar method, the upper seam

should be worked first. This does not mean that no work can be done on the lower seams until the upper one is mined out, but means that the pillars of the lower seams must not be drawn until the upper seam has been worked out, unless there is a great thickness of rock between the seams which would entirely fill the gob and choke before the draw or subsidence reaches and damages the upper seam.

BARRIER PILLARS.

1650. Barrier pillars are large pillars left between the workings of adjoining mines. They may run lengthwise with the strike of the seam when one mine is below the other, and then they are simply large chain pillars. More frequently, they run parallel with the pitch, and separate two mines located side by side. Barrier pillars are formed by each mine leaving one-half the required thickness on each side of the boundary line.

1651. For finding the width of barrier pillars in anthracite seams, the following formula, adopted conjointly by the chief mining engineers of four of the leading anthracite companies and the State Mine Inspectors, is recommended:

Minimum thickness of barrier pillar = (thickness of workings multiplied by 1% of depth below drainage level) + (thickness of workings multiplied by 5).

Thus, for a seam 6 feet thick, 500 feet below drainage level, the minimum barrier pillar should be $(6 \times 5) + (6 \times 5) = 60$ feet.

As the crushing load of an average bituminous coal is only about one-half that of anthracite, the formula given above can be used to determine the minimum thickness of a barrier pillar in a bituminous seam by simply doubling the result. Thus, in a bituminous seam of average hardness, 5 feet thick, and 400 feet below the drainage level, the barrier pillar should be $\{(5 \times 4) + (5 \times 5)\} \times 2 = 90$ feet.

1652. Good judgment must be used in determining the size of barrier pillars in bituminous seams, owing to their

varying degrees of hardness. For very soft coal, the pillar must be larger than for a firm, hard coal under the same conditions. When the barrier pillar is formed on the strike of the seam, it should be larger than when formed on the dip. It is impossible to formulate a rule to meet all conditions. The rules given are merely for general guidance. They will usually be found safe for determining the minimum thickness of the pillar required.

APPROACHING ABANDONED WORKINGS.

1653. Under all circumstances, in openings approaching old workings in which gas or water under pressure is likely to be encountered, special precautions must be taken. Accurate surveys and maps, while of great value as guides, should not be relied upon entirely. The opening approaching the old workings should not be over 12 feet wide, and bore-holes should be kept at least 20 feet in advance of the face. There should be one bore-hole in the center of the face running in direct line with the opening, and at every 8 feet of advancement of the face, flank-holes should be put in on each side. These flank-holes should deflect from the line of the opening from 25° to 30°, as shown by Fig. 511. When the seam is very thick, two or more sets of holes, one above the other, should be put in. All men engaged in this work should carefully watch for all symptoms of an increase of

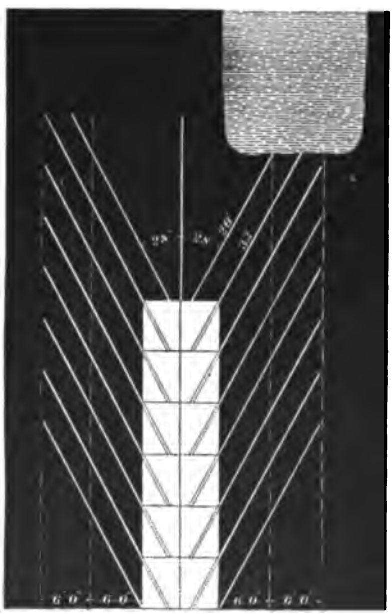


FIG. 511.

water or gas, and plugs should be kept handy, to stop up the holes in case water or gas is struck. Only safety lamps should be used at the face. In no case should more than one opening be driven towards old workings containing water or gas. In pitching seams, when the relative elevations of both the old workings and the new are approximately known, flank bore holes are necessary on one side only. When the seam has a very heavy pitch and the coal is free, much longer holes are necessary to ensure safety.

PROPPING.

POSITION OF PROPS.

1654. The tendency of the roof is to fall in the direction of the force of gravity, in the line *b g* (Fig. 512). But where the roof is solid and holds together, like that in

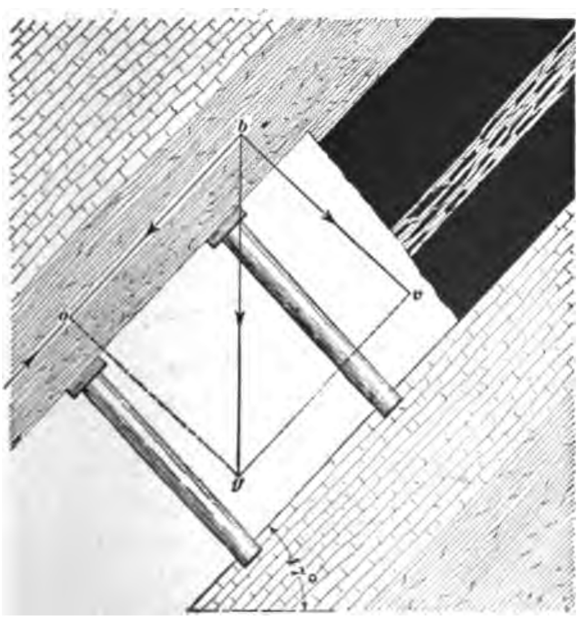


FIG. 512.

Fig. 512, this force of gravitation, represented by line *b g*, is resolved into two forces, represented by the line *b o*, parallel to the dip of the seam, and the line *b v*, at right angles

to the dip. As the line *b o* is equalized by an opposing force inherent in the roof itself, the only force or pressure to be provided against is that represented by *b v*; and as the resisting force of the floor is greatest in a direction at right angles to its inclination, it follows that the most effectual position for posts and all props to support the roof is at right angles to the dip of the seam.

1655. It will be noticed by comparing Figs. 512 and 513 that the force represented by the line *b g* is constant, being due to gravity, and that the force represented by the line *b v*, which represents the component of the force *b g*,

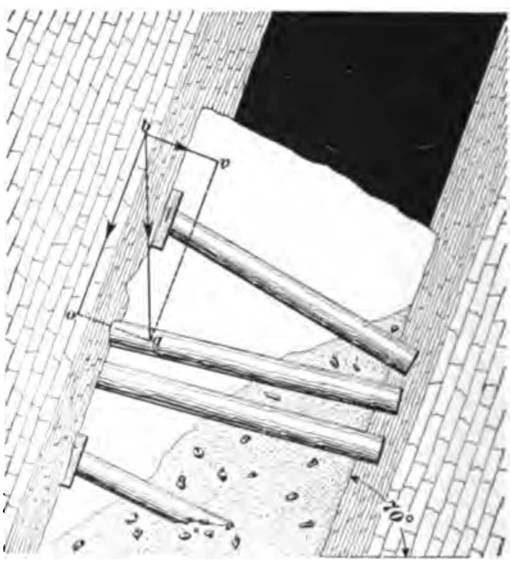


FIG. 513.

acting perpendicularly to the seam, varies inversely as the inclination. From this it is clear that, the greater the inclination, the less the weight upon the props.

In practice, posts are not set at right angles to the pitch, but are slightly inclined up the pitch so that they will tighten if any sliding of the roof takes place.

1656. The following table shows the maximum and minimum angles at which props should be set on varying inclinations :

Dip of Seam.	*Underset at Prop.	
	Minimum.	Maximum.
6°	0°	1°
12°	0°	2°
18°	1°	3°
24°	1°	4°
30°	2°	5°
36°	2°	6°
42°	2°	7°
48°	3°	8°
54° and upwards.	3°	9°

* Underset means that the head of the prop leans up the pitch, and the angles given show the deflection from a line at right angles to the floor.

SETTING PROPS.

1657. Props in some districts are invariably set with the thick end upwards. In respect to efficiency, one end is as well upwards as the other, as resistance equals pressure, and the strength of the post corresponds to its thinnest sectional area. By placing the thinnest end of posts in the floor, a smaller foot-hole is required, which will consequently take less time to cut out. Being more solid and stronger at their thick ends, props, when being set, are better able to bear the blows on their head when set with the thick end upwards. Some managers set the thick end down, while others set the larger end against the weakest stratum, be it top or bottom.

1658. Props for thick seams are usually rounded at the bottom to fit the foot-hole cut in the floor. Props are rounded in heaving bottoms to prevent their "mopping," i. e., being splintered at the bottom.

In seams of moderate inclination, where the bottom and top are both hard, props are set on foot-pieces which are placed on some loose material which acts as a cushion for the prop until the weight is uniformly distributed over the props. If one prop is tight to the top and bottom, while the others are only moderately so, the tight prop must "mop" or give way. Props should be set from the rise, i. e., the foot of the prop should be placed in position with the head up the pitch, from which position the head of the prop is raised to the roof.

1659. In many cases there is very little pressure on mine props in the first working, while in others a heavy weight will be noticed in a few days by the weaker props giving way in their weakest part. Where the top is fairly strong only a single prop and cap is needed; but, where the top is loose and jointy, either cross-bars or long, strong caps are required. Cap-pieces for wedging posts tightly to the top and bottom are indispensable. They extend the supporting area if they are thick enough and extend beyond the prop. They are, also, of great value as cushions, into which the prop can squeeze when weighted; hence, the post lasts longer without cracking or bending.

GANGWAYS, LEVELS, HEADINGS, OR ENTRIES.

MAIN ROADS.

1660. In inclined seams of considerable thickness, levels can be driven any height, but in the thinner coals the height is determined by the thickness of the seam. Gangways in the anthracite district of Pennsylvania are generally 6 or 7 feet high, clear of the rail, and from 10 to 12 feet wide. In soft-coal mines, the height is variable; the haulways where mules are used are seldom less than $5\frac{1}{2}$ feet and are sometimes 9 feet high, and their width varies from 8 to 12 feet.

1661. Some managers prefer that the main roads driven from the shaft bottom or slope landing shall follow the strike of the seam in all its variations, allowing sufficient rise (1 in 200 to 1 in 100) for drainage. This necessarily makes a

very crooked and undesirable road for the application, in the future, of mechanical haulage, although it may be advantageous for the limited use of mule haulage. The application of mechanical haulage should be considered when making a new opening. This would imply that all haulage roads should be as straight as possible, care being taken to avoid even small curves. In many mines the headings are driven on line. "Sights," or plugs with nails in them, from which plumb lines are hung, are placed in line in the roof, near one side, so that the passage of mine cars does not interfere with them.

The grade of the haulage road should be kept uniform throughout by cutting through small irregularities in top and bottom. The little expense incurred will be amply rewarded by the smoothness and rapidity of the haulage of the coal. Where the seam is flat, there may be a great many irregularities, such as local swamps, faults, etc., which render it out of the question to maintain a regular grade throughout. In such cases, the grade should be made uniform between certain points. A road may, in some mines, have many different grades which will not be very objectionable if the road is straight—only a few pounds more of steam are involved, if mechanical haulage is used. Crooked roads soon wear out ropes or chains. In some coal mines where large quantities of gas are given off, large airways—gangways, levels, headings, entries, aircourses, etc. —are required. With a weak top these are best secured by increasing the height, but in case of a strong top, extra width may be taken from the sides.

TIMBERING LEVELS.

1662. In flat seams, the manner of timbering entries, etc., is pretty much as described for drifts, while in pitching seams, different forms of timbering are resorted to. Much depends upon the angle of dip and the thickness of the seam. Round timber, being so much stronger and requiring less preparation for use than square timber, is generally used in timbering levels. The timber used in

gangways is usually from 9 to 15 inches in diameter. One great difficulty in timbering is found in the fact that timber too small is frequently used. Often, where 15-inch timber is really required, 10 to 12-inch timber is used. The angle between the legs and collar depends upon the method of timbering. However, the legs usually incline inwards 3 or 4 inches to the foot. The kind of timber used will depend largely upon the locality in which the mine is situated. Oak, chestnut, hemlock, cedar, and spruce are largely used.

1663. Fig. 514 shows the method of timbering the levels in thin pitching seams. The airway is driven on the dip side, and is, therefore, also used as the watercourse. The top is supposed to be weak. The legs *l*, *l* and the col-

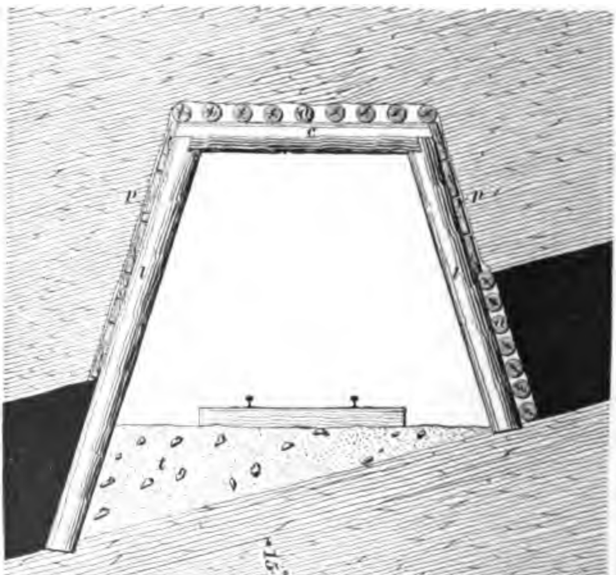


FIG. 514.

lar *c* are made of round timber about 12 inches in diameter, and are so jointed together that the collar *c* will stand great pressure. The laggings *a*, *a* are round poles taken direct from the woods, and are usually from 3 to 6 inches in diam-

eter. They are used to keep the loose coal and roof from falling between the sets of timbers, which are from 3 to 5 feet apart. Where the lateral pressure is slight, planks *p*, *p* are used. The road is made level by filling in the low side with refuse *t*, as shown in the figure.

1664. Fig. 515 shows the arrangement when the top is hard. If the seam were 4 feet thick, it would not be

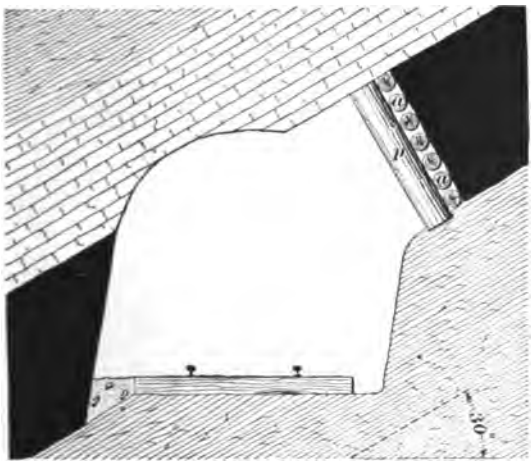


FIG. 515.

necessary to break into the top. When the bottom is soft and too much of it is taken up, there may be trouble in keeping the rise side of the road in good condition. The post *p* is simply used to support the laggings *a*, *a*.

1665. Fig. 516 shows a level in a seam of moderate thickness with a fairly good top. When the mine produces a great deal of gas, it is necessary to have gangways of large sectional areas in order to get an adequate supply of air. This is accomplished in low seams by driving the levels wide and placing the road to one side, and setting posts near it to support the roof, as shown in Fig. 516, in which case it will be noticed that the post *p* is set vertically with a good hold in the roof.

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1666. Fig. 517 shows the "Post and Bar System." It

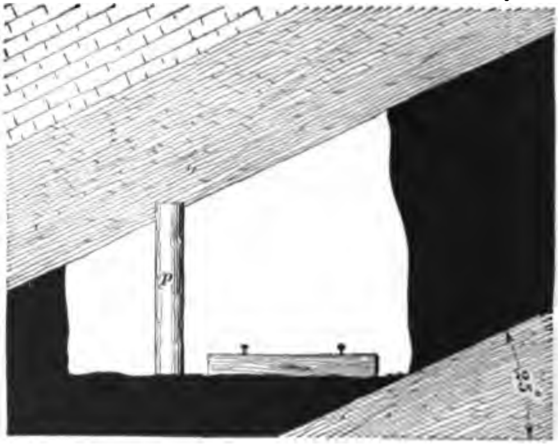


FIG. 516.

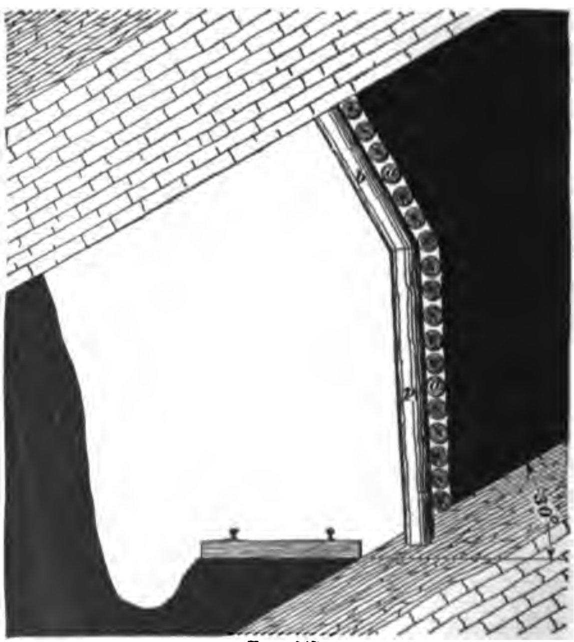


FIG. 517.

is open to many objections. The jointing of the post *p* and bar *b* is necessarily weak, but where the pressure upon the

laggings *a*, *a* is not very great it may be convenient. The roof is supposed to be strong.

1667. Fig. 518 shows the timbering used in thick seams of frail coal with a tender roof. Both legs *l*, *l* are the same

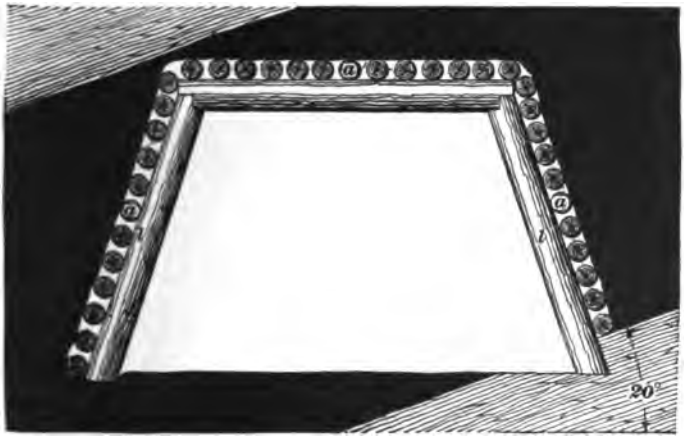


FIG. 518.

length, and laggings *a*, *a* are placed all around the set of timber.

1668. When the coal is very firm but the roof tender,

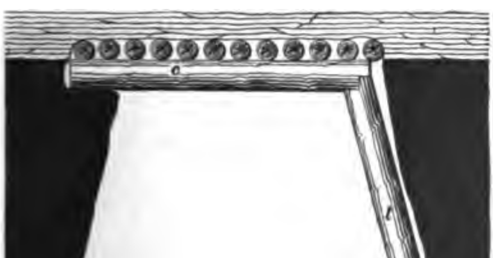


FIG. 519.

one leg of the timber may be left out, as Fig. 519 shows.

In some cases both legs can be dispensed with. Whether the collar *c* can be used alone or one end of it supported by a leg *l* can be determined by the relative cost of forming the holes in the top of the seam, so as to get the collar in place, and of setting and supplying the leg.

1669. Fig. 520 shows the method of timbering when the angle of dip is great, the bottom hard, and the seam is not thick enough to give full height for the entry. This

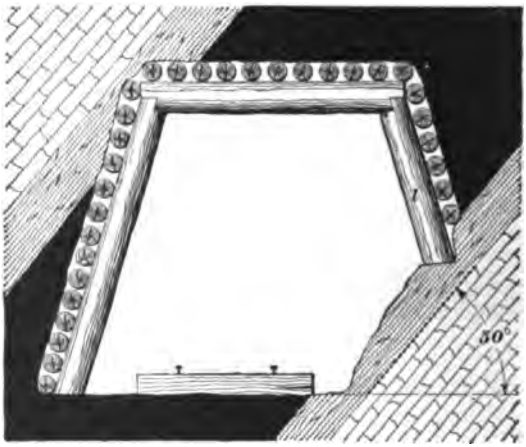


FIG. 520.

method very much reduces the cost of taking out enough rock to get in a set of timber having equal legs. The shorter leg *l* is given a firm hold on the rock bottom. The set of timber resembles that of Fig. 518.

1670. Fig. 521 shows a form of timbering used in pitching seams where the coal is soft, and falls to a height greater than that required for the gangway. The leg *l* on the high side is made long enough to reach up to the roof to support the laggings *a*, *a*, which keep the soft coal from continually sliding down into the gangway. The collar *c* strengthens the leg *l*. The coal is allowed to fall off on the low side where no lagging is necessary.

1671. Fig. 522 shows a method of timbering a level when the conditions are nearly similar to those in Fig. 520.

The inclination, however, is greater, and the top and bottom harder. The leg *l* is given a good hold in the bottom so that it will not be pushed out by the pressure of the coal.

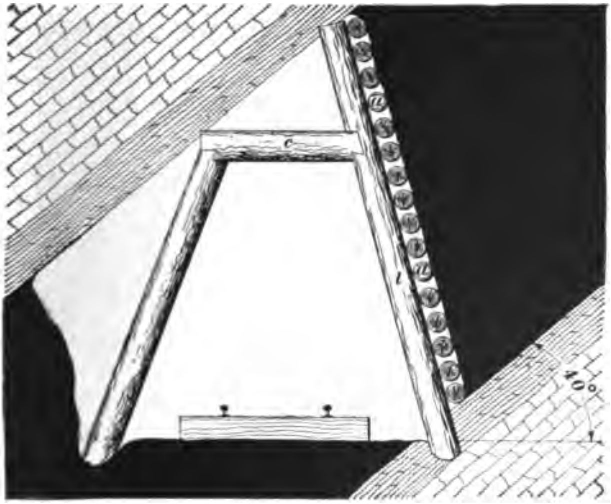


FIG. 521.

It will be observed that in this case the pitch is so great that the bottom on the high side is not disturbed, and the

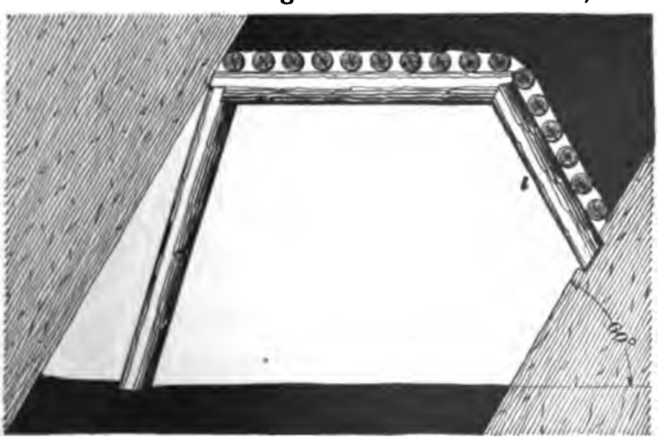


FIG. 522.

coal on the low side is allowed to fall away from the roof, as in Fig. 521.

1672. When the side pressure is great, the power of

FIG. 523.

resistance is much increased by placing a second horizontal piece *a* between the two legs *l*, *l*, as shown in Fig. 523. This

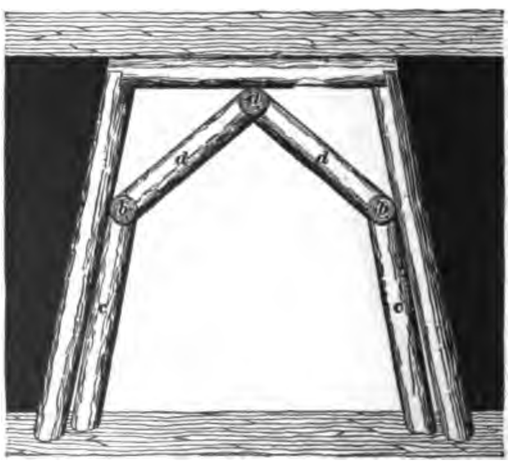


FIG. 524.

prevents the lateral pressure from splitting the legs at their upper ends.

1673. Figs. 524 and 525 show forms of timbering capable of resisting enormous pressure. The operation of fixing the braces inside the regular set of timbers is as follows: The longitudinal timbers *a*, *a*, immediately under the cap or collar, are put in place and temporarily held there by pieces of wire. The length of each piece is about 10 feet. Next to the two sides, longitudinal pieces *b*, *b* are placed and

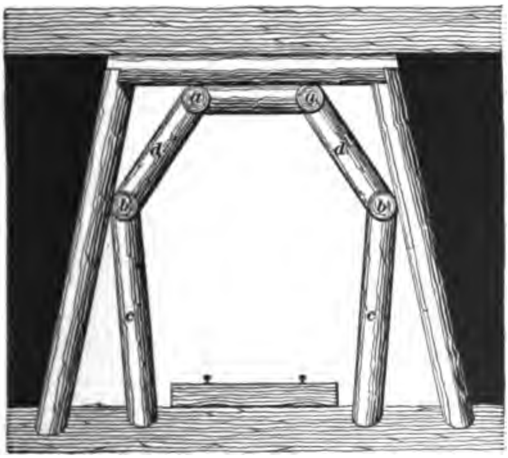


FIG. 525.

temporarily held in position also by pieces of wire. Two or three struts *c*, *c* are then placed under the side longitudinals, and afterwards some of the upper struts *d*, *d* are inserted obliquely and driven towards their permanent positions. The wires are now removed, and the remaining struts are driven firmly into their places. The lower ends of the struts *c*, *c*, Fig. 525, are set away from the timbers for the purpose of further strengthening the resistance to lateral pressure.

UNDERGROUND ROADS.

TRACK LAYING.

1674. Good solid roads are essential features of a well-managed mine. It is difficult to get a large tonnage of coal over poor tracks, and the damage to cars, etc., is such an item of expense that this one consideration of good tracks may decide whether or not the operation will be a financial

success. The weight of the rail, width of the gauge, the nature and shape of the switches, etc., depend on (1) the size of the mine car, and (2) the method of hauling. High speeds require heavy rails, solid roadbeds, and specially devised switches. The rails should be in good alinement, and the ties should be carefully bedded so that they will be solid and not allow the rail to yield under the load. Ties are best made of oak, which is durable and takes a tenacious hold upon the spikes which are driven into it to secure the rail. Ties are usually from 4 to 6 inches deep and 6 to 8 inches wide, and are generally placed from 18 to 30 inches apart, from center to center.

1675. Gauge.—In Great Britain, the gauge in most general use is 24 inches, but variations from 18 to 30 inches are frequently employed. In America the variation is greater, the gauge ranging from 30 inches to 4 feet 8½ inches. It is generally admitted that a gauge of more than 4 feet can but seldom be economically employed, and one less than 30 inches is undesirable. The gauges in most common use are 30, 33, 36, 42, 45, and 48 inches, but other intermediate gauges are used. It is claimed that the greater stability of wide gauges reduces the expense, because the capacity of the car is increased, the outlay for rolling stock is reduced, as is also the cost of repairs. Again, it is claimed for the narrow gauge that the ease of hauling around sharp curves, the reduction in cost of construction, and the use of mine cars with inside wheels are advantages greater than those advanced for the broad gauge.

The height of the seam and the nature of the roof are factors that enter largely into the determination of the gauge.

1676. Rails.—Wooden rails are now only used in roomroads, and even there they are frequently covered with strap-iron if not replaced by light steel **T** rail. Iron **T** rails are falling rapidly into disuse. Steel **T** rails are manufactured in America for mine use in sizes varying from 8 to 45 pounds or more per yard of their length. Where the cars

do not carry over 2,000 pounds and mule haulage is in vogue, the size used generally is 12 to 30-pound steel **T** rail, but for heavy loads or great speeds the size varies from 30 to 45 pounds. The 8-pound rail is only used in rooms, and where there is little traffic.

On steep roads, where the cars must be lowered by hand, i. e., by brake, or sprags, a wooden rail is laid close alongside the **T** rail to increase the friction.

Rails are manufactured in irregular lengths, generally from 12 to 30 feet, and when laid on heavy inclines they are always joined together by fish-plates; but on level roads, with good, hardwood ties, fish-plates are seldom necessary to keep the rails well butted together if the rails are of the right weight.

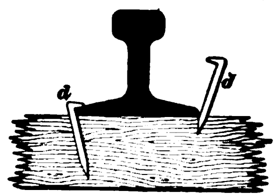


FIG. 526.

In America the **T** rail is spiked directly to the ties by hook-spikes *d*, *d*, Fig. 526. In Great Britain and elsewhere, the base of the rail has a hole punched, or a notch cut, in the side to receive the hook-spike. This, they claim, prevents longitudinal movement. Both spikes on the inside of the road should be driven in the same side of the tie, and those on the outside of the rail in the other side of the tie, in order to keep the ties square across the road.

SWITCHES.

1677. The switches used in coal mines are somewhat different from those used on the surface. It is of great importance that they be made as strong and as simple as possible so as to require but little attention from the drivers.

Switches used on the main haulage roads are quite similar to those used on railroads, while those used in the productive branch roads are usually made with no movable parts. A description of the most common ones in use will now be given.

1678. Fig. 527 shows a switch used in low seams where the car is delivered on the main track by hand. The tongue

a has a slight projection on its under side to prevent it slipping off the rail *b* until raised by hand. The one objection is that if the tongue is not laid off the rail before the trip passes, it will derail the whole trip. The cross-latch *c* must be removed by hand also.

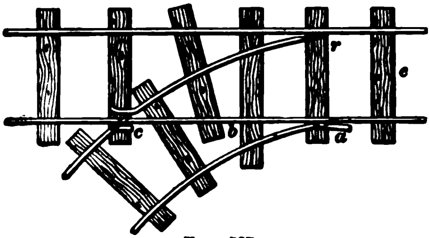


FIG. 527.

The tongue *a* should be set sufficiently far in advance of the point *r* so that, when the car is approaching the switch from the point *e*, the wheel will have run up the latch *a* far enough to raise its flange above the rail *b* before the wheel on the other side strikes the point *r*. When the car is to be taken over the switch, the latches *a* and *c* are put in the position indicated by the dotted lines, and the car, as it approaches the switch, is given a shove so that the flange of the wheel will pass inside the point *r*, and the car be sure to take the switch-track. This switch has the advantage of leaving a straight, unbroken line of rails for the main road which does not need to be relaid when the switch is taken out, and, further, full-length rails need not be cut to suit the switch, thus saving much waste of good rails.

1679. Fig. 528 shows a switch with a cast-iron frog *f*, and fixed points *a* and *b*. It is used principally in butt headings where the car carries a heavy load. The advantage of this kind of a switch is that it has no adjustable pieces about it, and consequently requires no attention from the driver.

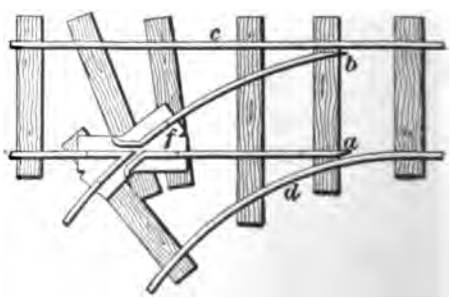


FIG. 528.

The difficulty with this switch is that the flange of the wheel is liable to catch the point *b*, while the car is running along the straight road,

and either derail the car or cause it to run in the switch. This, however, can usually be avoided by making the rail *c* somewhat lower than the rail *a*, thus causing the car while passing to cling to the rail *c*, and readily pass between the point *b* and the rail *c*, and at the same time causing the wheel on the opposite side to take the rail *a*. Another great trouble experienced with this kind of a switch is that where the wheels are allowed to remain on the cars after grooves have been worn in their treads, the wheel will invariably follow the rail *d*. The point *b* should be higher than the rail *c*, so that the tread of the wheel will not strike the rail *c* while the car is leaving the switch; similarly, the point *a* should be higher than the rail *d*, so that the tread of the wheel will not strike the rail *d* while the car is running along the straight road in the direction from *f* to *a*. The rail *c* being lower than the rail *a*, it is obvious that when a car is to be taken in the switch, the driver will have to push the car towards the rail *d* so that the wheel will take the rail *b*, and the flange of the wheel on the opposite side will pass between the point *a* and the rail *d*.

This form of switch is not applicable in the case of mechanical haulage, because it does not give an unbroken main line, which is essential to the steady movement of the trip.

1680. In laying a switch great care should be taken regarding the relative heights of the lead and follower rails. Where the switch is laid to the dip side of the heading, and the loaded cars must be pulled from the dip over the switch, the follower or inside rail should be the higher; while in the case where the switch is laid to the rise side of the heading and the loaded cars will run over it, the lead rail should be the higher.

1681. When the switch is not to be in constant use, a latch *c*, Fig. 529, is used instead of a frog. The switch shown in Fig. 529 is open to the charge of making a broken main road, but it is not liable to derail loaded cars, as the latches will be adjusted by the cars when traveling

outwards, if the speed is not great. When this form of switch is used for a turnout, the lead rail *a* is made about double the length of that used for a room. The length of the lead rail is determined in all cases by the radius of the curve where the switch is to be laid.

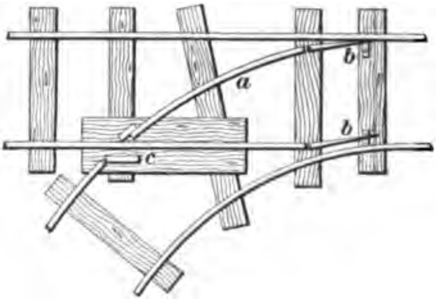


FIG. 529.

The tongues *b*, *b* are sometimes connected by a rod attached to a lever, so that they may both be moved at once from the side of the track, or by a person stationed some distance away. Where the traffic is all in one direction, as in turnouts, the tongues are kept in one position by a spring-pole spiked alongside of the track.

1682. Fig. 530 shows a double switch sometimes used in some parts of the anthracite coal fields of Pennsylvania.

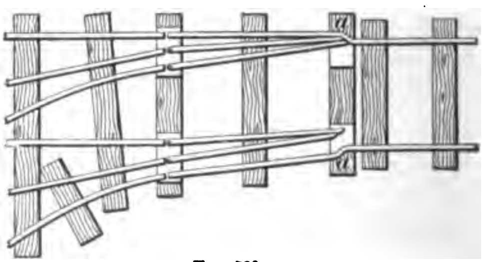


FIG. 530.

It can not be highly recommended, in any case, for inside switches. The short curves or "kinks" in the rails at the points *a*, *a* will derail the cars while passing outwards, if they are running at a high speed.

1683. Fig. 531 shows a rough and ready arrangement where a turnout or any other condition requires the temporary use of a switch. The ordinary form for narrow gauges consists of a movable rail *a*, about 6 feet long, pivoted

on a center *b*. Where the curve is not great, this arrange-

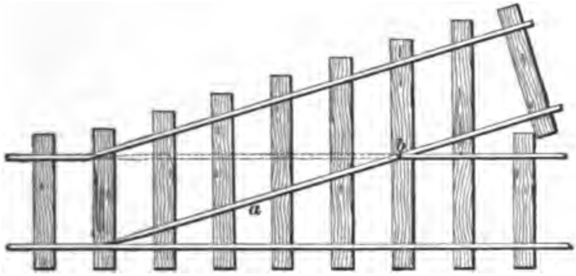


FIG. 531.

ment acts admirably. The dotted line shows the position of the rail *a* when the straight road is in use.

1684. Fig. 532 shows an excellent switch for permanent tracks in coal mines. No frog or latch is required. By

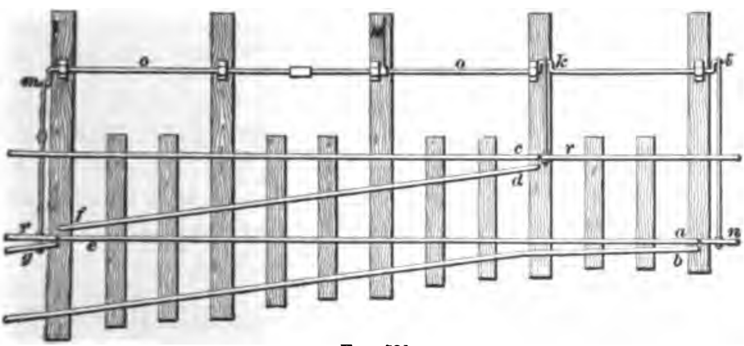


FIG. 532.

throwing over the lever *h*, the throw-rod *o* moves the throws *i k m*, so that the rails *r* will face the rail *d f*, the rail *n* will face the rail *b*, and the rail *g* will face the rail *f*.

The lead and other rails can be reduced to any required length to suit circumstances. When the lead rail *f d* is from 12 to 16 feet long, and the other lengths are in proportion, the switch gives excellent results. It should not be made of less than 20-pound rail, and heavier will suit better. By this device, it is seen that no frog is needed, and the joints are broken, i. e., they do not occur opposite each other, or on the same tie.

1685. Fig. 533 shows the ordinary stub switch, much used in coal mines. When the lever *l* is thrown over, the

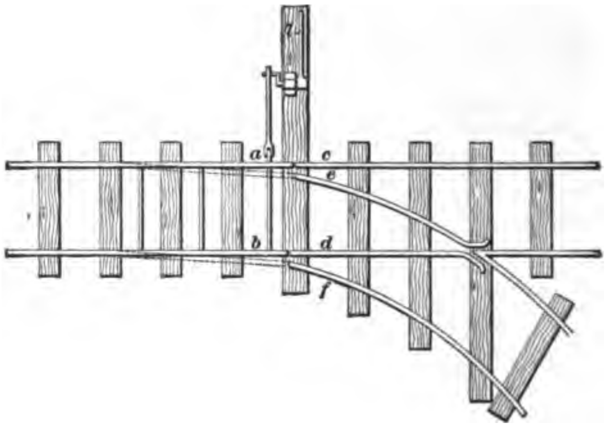


FIG. 533.

rails *a*, *b*, now facing *c*, *d*, are made to face rails *e*, *f*, as shown by dotted lines.

1686. When two tracks cross each other at any angle the same arrangement is used in mines as in railroads. They are called **grade crossings.** Fig. 534 shows a form which is self-explanatory. The cars must pass over this crossing slowly because the roads are broken.

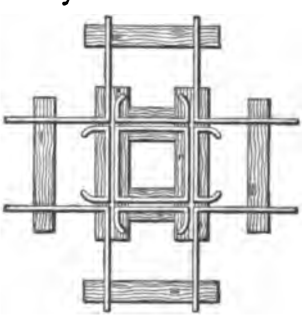


FIG. 534.

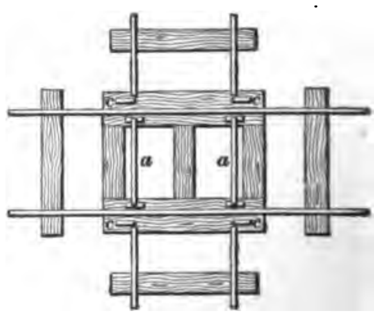


FIG. 535.

1687. When a subordinate road crosses a main road, along which the cars pass rapidly, the main road is left unbroken and the subordinate road is built the height of the

rail higher than the main road, and a crossing like that shown in Fig. 535 is used. The cross latches *c* are sometimes held in place by blocks placed at the ends of the short rails inside the main track, as shown at the end of the rail *a*, Fig. 529. However, it is best to hold the latches in place by an iron plate having a shallow groove and placed at each end of the short rails *a*, *a*, so that, in case of neglect to take the latches off the main track, the cars going either way along the main track will remove them and prevent the trip from being derailed.

1688. Fig. 536 shows a convenient switch arrangement for the foot of inclined planes. A uniform grade is continued down to point *A*, and from that towards *B* the grade is just sufficient to cause the cars to clear the switch. In the loaded track *D* the grade is such that the full cars will gravitate from the point *D* to the point *A*. The movable rails *a*, *a* are bound together at each end by clamp-rods or spreaders, or bridles, and securely fastened in the center so

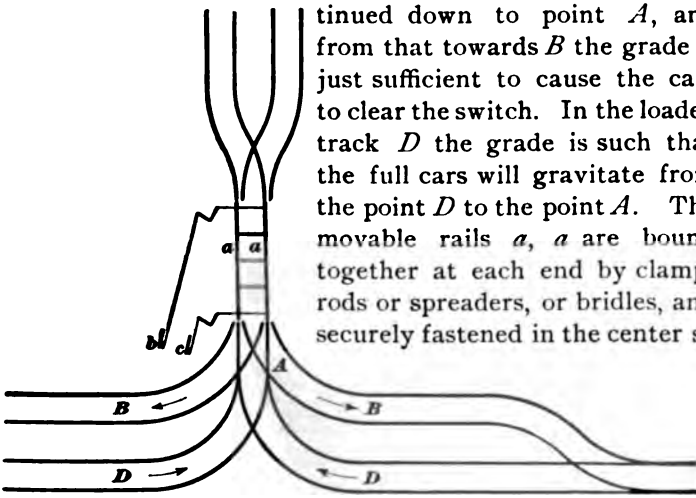


FIG. 536.

that they can not slip longitudinally. By using levers *b* and *c*, the rails *a*, *a* are adjusted to suit the road on which the trip is to travel. Care must be taken not to make the mistake of sending the trip upwards on the same track on which the down trip is descending.

1689. Fig. 537 shows a plan *A* and a profile *B* of a method of connecting the roads of a level, or gangway, to the road in the slope. At a distance of forty to fifty feet above the landing, or gangway *g*, the slope *s* is widened out

to accommodate the branch *b* leading into the landing loaded track *l*. This branch descends with a gradually lessening grade, until at the level of the gangway it turns into the main loaded track. A short distance above the gangway a bridge or door *d* is placed, which, when closed, forms a latch by which the empty cars are taken off the slope. The empty track *e* is about 6 feet higher than the loaded track *l*, and is carried over it on a trestle.

The figure shows in particular the plan as arranged for a single slope, or one side only of a slope taking coal from both sides. When coal is being raised from this landing, the bridge is closed; the empty cars come down and are run off over the bridge, the cars are unhooked from the rope, and the hook and chain are thrown down to the track below on which the loaded cars are standing; the loaded cars are attached and the cars are hauled to the main track on the slope. This plan can only be economically employed in

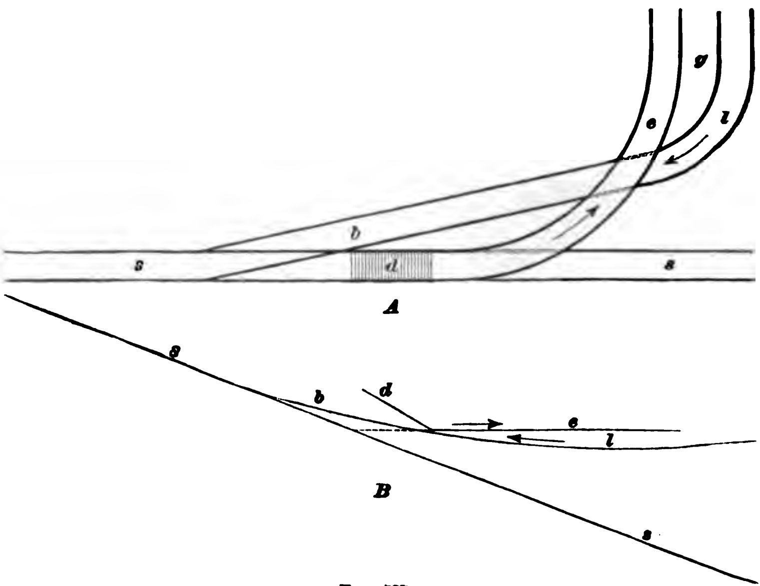


FIG. 537.

thick seams, as the height necessary to allow one track to cross the other on a trestle can not be obtained in seams of

moderate thickness without taking down a large amount of the top. By this method the cars can be handled on the landing by gravity.

1690. Fig. 538 shows an excellent method of laying switches in either thick or thin seams where the pitch does not exceed 20°. When there is only one track in the slope and coal is hoisted from both sides, the same arrangement is used on each side; but to avoid complications, such as crossings, etc., it is best to have one landing or lift just the length of the switch on the main track further down the slope, as indicated by the dotted lines. The loaded track *l* and the empty track *e* join before they strike the track *s* in the slope.

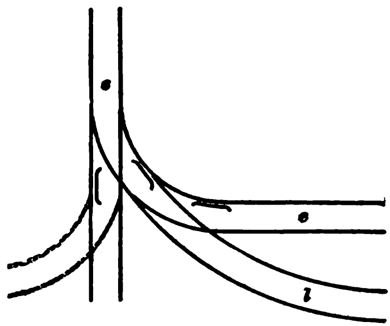


FIG. 538.

1691. Fig. 539 shows a plan *A* and profile *B* of a switch

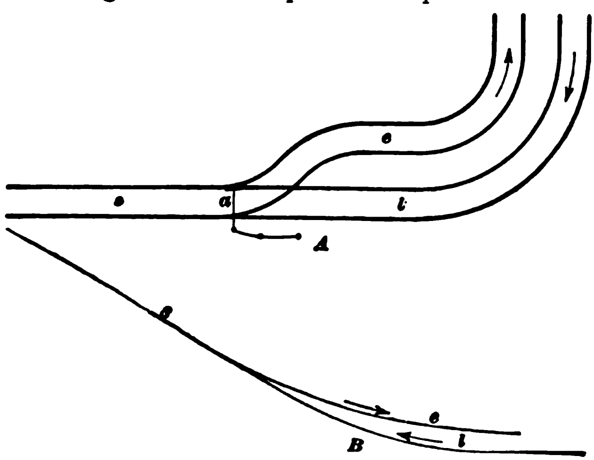


FIG. 539.

used at the bottom of a slope. The figure shows one side only of the slope, the other side being similar. At the

junction *a* of the two roads there is a pair of spring-latches, causing the empty cars as they descend the slope to take the road *e*. The empty cars pull the rope in to where it can be attached to the loaded cars which are standing near the slope on the road *l*.

1692. Fig. 540 shows a plan of the switches at the bottom of a slope in which double tracks are used. The two tracks in the slope *s* unite at the point *p* where there are

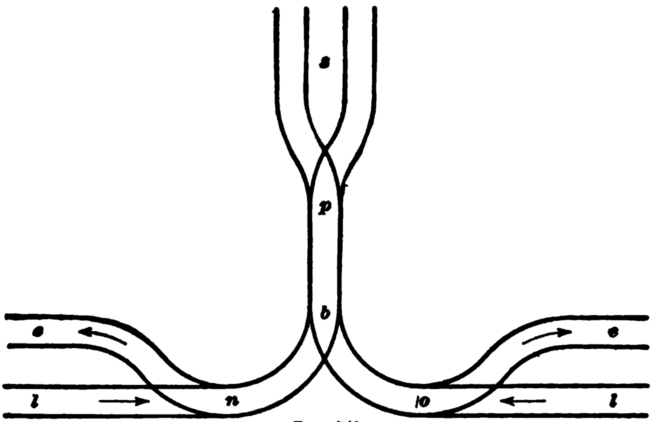


FIG. 540.

latches set by the cars; then at the point *b* two roads branch off, one to the right and the other to the left; and, finally, at the points *n* and *o*, empty tracks *e*, *e* branch off the loaded tracks *l*, *l*. The latches at the point *b* must be set by hand, while those at the points *n* and *o* may be spring-latches. The descending empty trip should have sufficient momentum when it reaches the bottom to run along the road *e* far enough to clear the track for the loaded cars standing on the track *l*.

1693. Fig. 541 shows a plan by which the switches at the bottom can be so arranged and graded that the cars can be handled by gravity. At the points *a*, *b* spring-latches may be placed; while at *p* the latches must be set by a lever, for the loaded cars coming from either of the loaded tracks *l*, *l* must be sent up the road *a* or *b*, depending upon which

the empty cars last descended. The latches at *j* are set by the cars which pass over them only one way. It will be observed by examining the figure that the empty cars must take the empty track *e* on that particular side on which they are descending. This requires that an equal number of

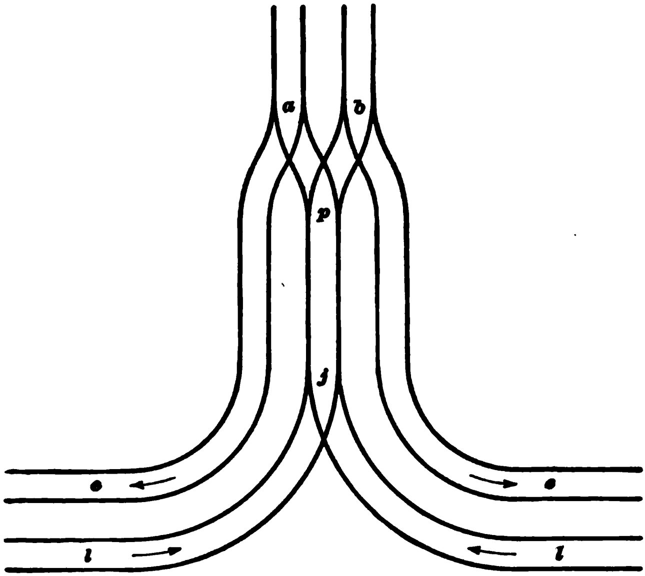


FIG. 541.

loaded cars are supplied by each side. Sometimes the loaded tracks *l*, *l* are connected by a straight track across the bottom of the slope, for the purpose of transferring cars from one side to the other in case one side does not furnish as much coal as the other. Although this plan requires width at the bottom of the slope for but three tracks, it necessitates an extra curve in the loaded tracks, which is an objectionable feature.

1694. The arrangement of the tracks on a slope should be such that there will be as few switches as possible on the slope itself; that the track will be unbroken; that there will be nothing standing at the bottom in line with the tracks in the slope; and that the cars can be handled at the bottom by gravity. The arrangement of the tracks

at the top of the slope is often similar to the bottom arrangement. It is always best, however, where there are two roads on the slope, to carry them over the knuckle instead of joining them, as is sometimes done, before they reach the knuckle and beyond which there are again two roads.

1695. When the pitch of the slope is so great that the coal falls out of the cars, a **gunboat** or a **slope-carriage** is used. The former is a special car into which the coal from the mine cars is dumped at the different landings along the slope and conveyed to the surface; and the latter is a car so constructed that, when it is placed on the slope, its top or floor will be horizontal. There is a track on the floor of the slope-carriage upon which the mine car is run. When the slope-carriage stops directly in front of a level, the empty car is taken off and a loaded one put on.

When more than one car is raised at a time, the slope-carriage has no track on it, but is covered with smooth plate iron. The landing is also laid with smooth plates. By this arrangement, with an empty and loaded track in the landing, 2, 3, 4, 5, or 6 cars are run on to the carriage without necessitating any movement up or down. The plate iron enables the cager to run the loaded car on at the upper end of the carriage and then slip it down to the end or against the next car, as the case may be.

1696. Fig. 542 shows the track arrangement of a shaft bottom where the cars are caged from both sides of the shaft. The loaded tracks *l*, *l* have a grade towards the shaft of from 1 to 3 per cent., depending upon the size of car and wheel used, while the empty tracks *e*, *e* are similarly graded in the opposite direction. When both sides of the shaft produce the same number of cars, the operation of caging is very much facilitated by the loaded car on the one side bumping the empty car off the cage on to the empty track on the other side; while, in the case of unequal production on the different sides of the shaft, the bottom man is frequently required to pull the empty car off the cage by hand to the side from which the loaded car is run on to the cage. In the

former case, if the roads and cars are in good condition, one

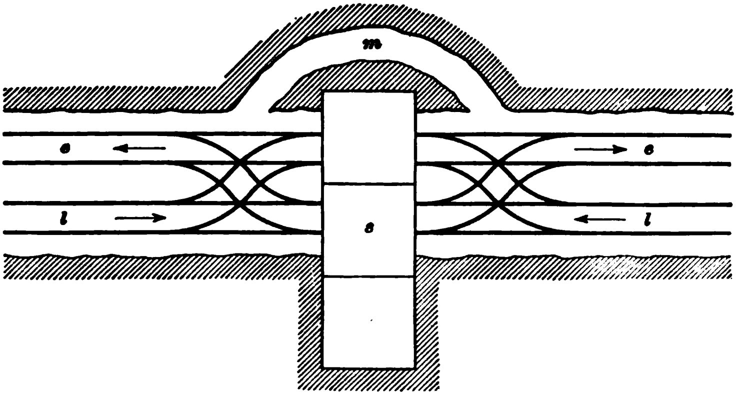


FIG. 542.

man on each side of the shaft can do the caging; but, in the latter case, both bottom men must be on the same side of

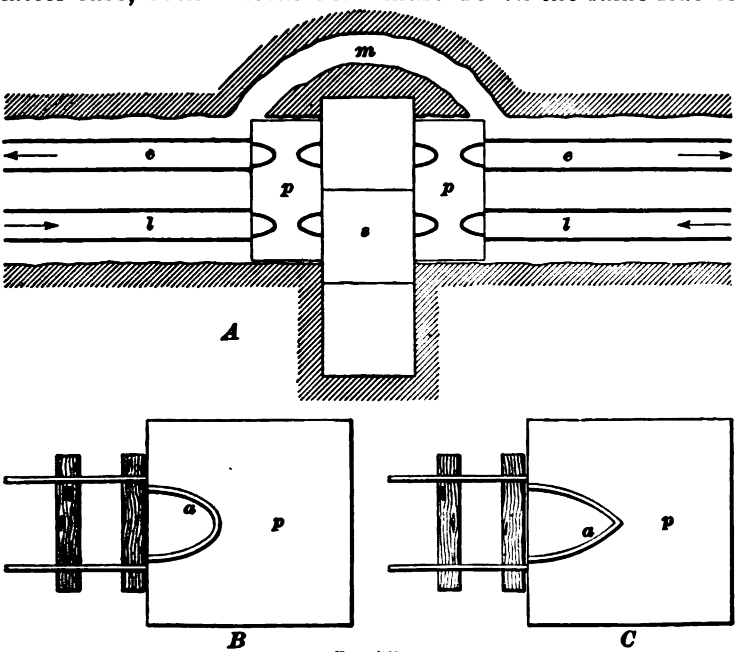


FIG. 543.

the shaft, and even then the two can not cage as easily or as

rapidly from the one side as the one could when both sides of the shaft were working equally. The manway *m* is used to pass from one side of the shaft to the other, as it is dangerous to pass through the shaft.

1697. Fig. 543 *A* shows the arrangement of the tracks at the shaft-bottom when plates *p*, *p* are used. The operation of caging is similar to that just described, except that the car is run on to the plate *p* and directed to the proper cage or track, as the case may be. The use of plates is limited to small cars holding not more than 1,600 pounds of coal. The grades on the loaded tracks *l*, *l* and on the empty tracks *e*, *e* are similar to the corresponding tracks in Fig. 542. The arrangement of the manway *m* around the shaft *s* is also like that in Fig. 542. *B* and *C* show two forms of tongues *a*, *a* placed upon the plates *p*, *p*, and their proper position in front of the tracks. The tongue *a* is raised about 1½ inches above the plate *p* and directs the flanges of the wheels so that the treads will take the rails as the car leaves the plate.

DAMS.

USE OF DAMS.

1698. Dams built in a mine are of somewhat different form from those erected on the surface, and, therefore, require special attention on the part of the mining student. They do not present, in general, very great difficulties. A full understanding of the conditions under which they are required, and the surroundings of their proposed location, is needed to determine their shape, the nature of the material of which they are to be constructed, and their size.

1699. The two principal requirements of a dam are: 1. That it shall be perfectly water-tight. 2. That it shall be capable of resisting the pressure that may be brought to bear upon it. That a dam may be water-tight, it must be constructed of impervious material, and the pressure must tend to close, rather than to open, the joints in the structure;

these joints must, moreover, be well calked to prevent the passage of water. It is also especially necessary to make the junction between the dam and the sides, roof, and floor of the passage in such a manner that the water can not force its way through it. To render the dam capable of resisting the pressure that may subsequently be brought to bear upon it, it must be constructed of strong materials, and these must be so disposed as to offer sufficient resistance without becoming deformed. It must be borne in mind in designing and erecting dams that the pressure to be resisted is usually very great, necessitating the best of materials and workmanship.

1700. Dams are used in mines principally for the four following purposes:

1. To keep back surface water.

2. To keep back the water from old workings or from an adjoining mine.

3. To flood a portion of a mine in case of a mine fire.

4. To keep back the deleterious gases given off by old workings.

LOCATION OF DAMS.

1701. A dam should be located in such a place as will secure all the following important advantages, or as many of them as possible:

1. The site chosen should be under a good strong roof and should have a solid rock bottom.

2. The pillars against which the dam abuts should be solid, and of such size as will provide sufficient lateral strength.

3. The dam should be located in a place where the strata will not be disturbed by subsequent mining.

4. It should be located at a place where the opening in the seam is as narrow as possible.

5. It should be located at an accessible place.

CONSTRUCTION OF DAMS.

1702. The construction of dams depends upon the amount of pressure they are to withstand, their probable life, the size of the dam, the time available for their construction, and the relative cost of the different materials.

The materials used in constructing dams in mines are wood, brick, or masonry, and their faces may be either straight wall or arched, depending upon the material used and the head of water.

1703. To understand the construction of dams to resist the pressure of water, it is necessary for the student to understand the following elementary principle of hydrostatics:

At any given depth the pressure of water is equal in every direction, and is in direct proportion to its vertical depth.

Thus, if a mine is flooded, and the *vertical* depth of the water is 100 feet, the pressure per square foot at the bottom is equal to the weight of 1 cubic foot of water multiplied by the depth in feet, or 100. Hence, $62.5 \times 100 = 6,250$ pounds per square foot. At a point half-way down, the water will press against the sides with a pressure equal to $\frac{100}{2} \times 62.5$ pounds $= 3,125$ pounds per square foot.

1704. Dams to divert the course of water, or to keep

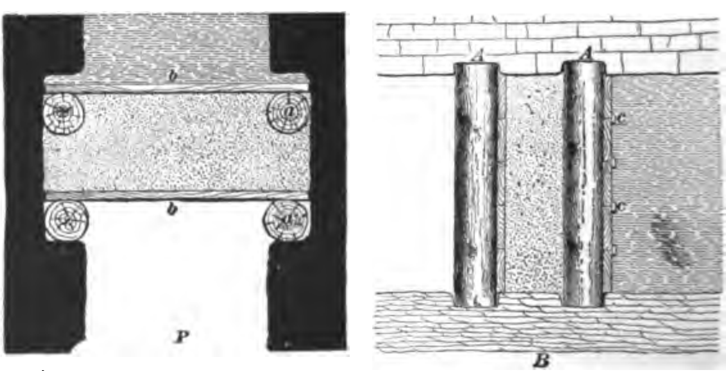


FIG. 544.

back gases, are subjected to very small pressures. In many

cases an ordinary stopping, such as is used to block an air-course, will suffice. This may be constructed of either wood, brick, or stone, the joints being made water-tight.

Dams to resist moderate pressures may be constructed of two walls of plank supported by props firmly fixed in the top and bottom, and with the space between filled with puddled clay. The joints of the planks should be battened on the side next the water. Fig. 544 shows a plan *P* and section *B* of such a dam, in which *a*, *a* are the posts, *b* planking, and *c*, *c* battens; puddled clay, which is from 1 to 2 feet thick, is also shown.

1705. Fig. 545 shows a wedge-shaped dam which is one of the best, and one which, under modifications according to circumstances, may be applied in most cases where any other dam can be effectively placed. This dam consists of pieces of wood, carefully dressed with a taper, and placed with the thick end next the water. The taper of each piece of timber depends upon the radius of the curvature of the dam, and is greater for dams of small radii. Each piece of timber should be tapered at the surface and properly numbered, so that when the separate pieces are taken into the mine they can readily be placed in their respective positions. Thoroughly dried timber should be used. The face of the dam is arched from side to side. The lengths of the pieces of wood depend upon the pressure which the dam will be required to resist, and also upon the area of the dam itself. They may vary from 3 to 8 feet in length and the *radius of the inner circle* of a wooden dam may be from 18 to 30 feet. Notwithstanding the most careful wedging, the pressure on the face of the dam is sometimes great enough to force the whole structure back. Therefore, it is advisable to so cut the sides of the passage that the forcing back of the dam will tend to wedge it still tighter.

1706. While the dam is being constructed, it is necessary to insert three iron pipes in it: one *a*, about a foot from the bottom, of sufficient size to carry off the feeder of water, or, if the feeder is very large, two pipes may be inserted; another *b*, about 18 inches in diameter, two feet

from the bottom, for the purpose of allowing the ingress and egress of the workmen during the insertion and wedging of the dam, and a third *c*, which should be from 3 to 6 inches in diameter, and placed near the top. A good, tight valve should be placed on its outer end. This pipe can be used as an air vent while the water is rising. If at any time it is desired to draw the water off slowly, the valve can be opened.

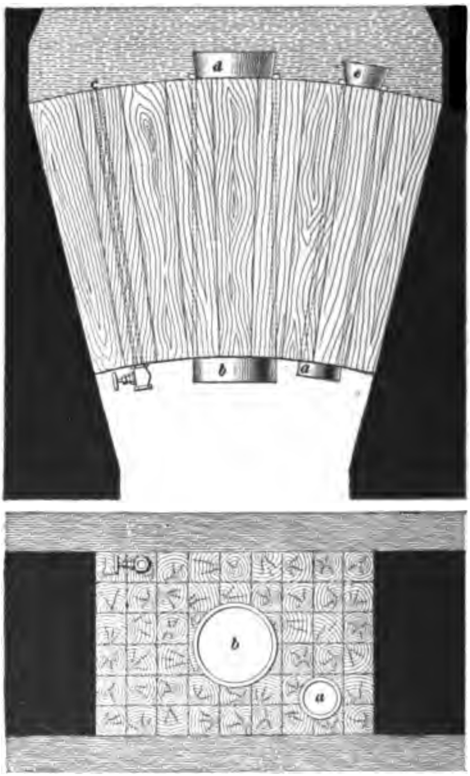


FIG. 545.

The sides, top, and bottom of the seat of the dam should be lined with tarred flannel, so as to ensure a water-tight joint on all sides. After the tapered timbers have been placed in proper position, the wedging is commenced on the inside with wedges 12 inches long and 3″ × 1″ at their heads. After these have been driven in at all the joints, and around the pipes, other wedges are driven in, of diminished size, as long as they can be entered, after which a chisel is used to prepare places for their insertion. The wedges must be perfectly dry. After the wedging is finished, the workmen drive the plug into the pipe *a* through which the water has been flowing. They then pass out through the pipe *b*, drawing after them the plug to close it, which has been placed

conveniently for so doing, and the work is completed. A dam of this description, 6′ × 6′ and from 6 to 8 feet thick, will resist a pressure of water of from 130 to 260 pounds per square inch. When the pressure is less, the dam may be made proportionately of less thickness, although under any circumstances rendering a wedge-shaped dam necessary, it would not be advisable to put in one less than 3 feet in thickness.

1707. Fig. 546 shows a sectional plan of a spherical dam built of brick and suitable for places where the coal, top, and bottom are hard. This dam is constructed of three concentric spherical arches dovetailed into the surrounding strata in such a manner that the elevation in a vertical section would have the same appearance as the plan which is shown, except that rock would be shown where the coal is shown on the plan. The object of forming a dovetail abutment is for the purpose of securing good support for the several arches of which the dam is composed, while at the same time cutting away as little of the surrounding strata as possible. The dam is 15 feet thick from *a* to *b* and has a maximum radius of about 30 feet. The arcs *g h*, *e f*, *c d* mark the spherical surfaces of the different arches which go furthest into the surrounding strata.

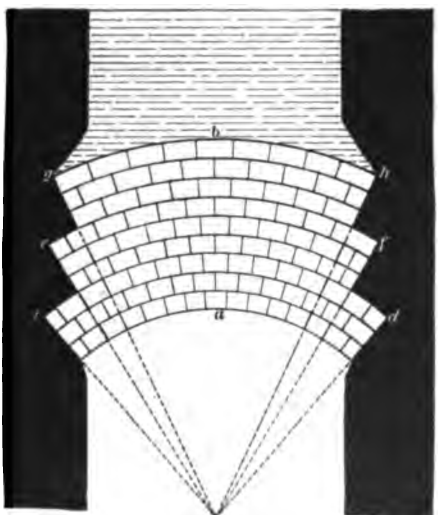


FIG. 546.

The radius of curvature of the arches of brick or masonry dams will depend upon the amount of pressure to be resisted and the size of the opening to be closed. For heavy

pressures, the rule is to make the radius *o a* equal to the height of the opening when trimmed up.

1708. Fig. 547 shows a plan of a brick dam built of two spherical arches *D*, *D* from 6 to 12 feet apart, the interspace being filled with puddled clay *a b*. This form of dam is suitable for bituminous mines, where the coal is soft. As in Fig. 546, a vertical section of this dam would also appear similar to the plan shown, except that the strata of the top and bottom would be shown where coal is shown on the plan. In this form of dam, the outer radius *o c* or *o d* should be equal to a similar radius *o a* of Fig. 546, and the thickness of each of the arches *D*, *D* should be at least one-half the thickness obtained by the formula which will be given later. Pipes should be inserted in brick or stone dams for the same reason that they are put in wooden dams. The puddled clay is inserted to prevent leakage, and to transmit the pressure from one wall to the other.

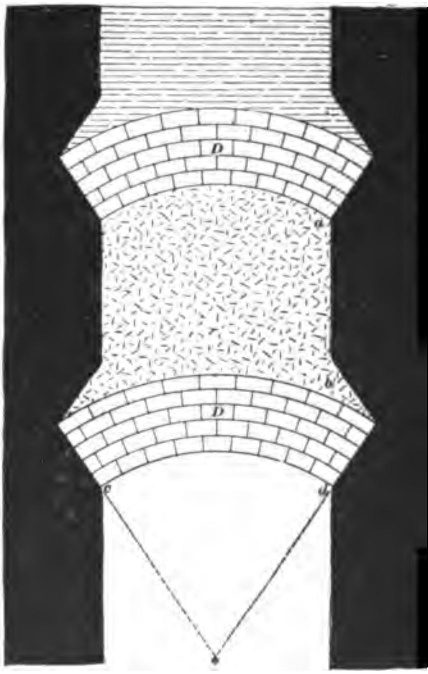


FIG. 547.

1709. Fig. 548 shows a plan *A* and section *B* of a cylindrical brick dam built at a colliery in the anthracite region of Pennsylvania, to shut off a large inflow of water through the strata in the roof close to the face of the chamber. There is considerable depth of wash, or drift, over the seam, and it was thought advisable to abandon, for a time, all mining at that level until the coal below was worked out.

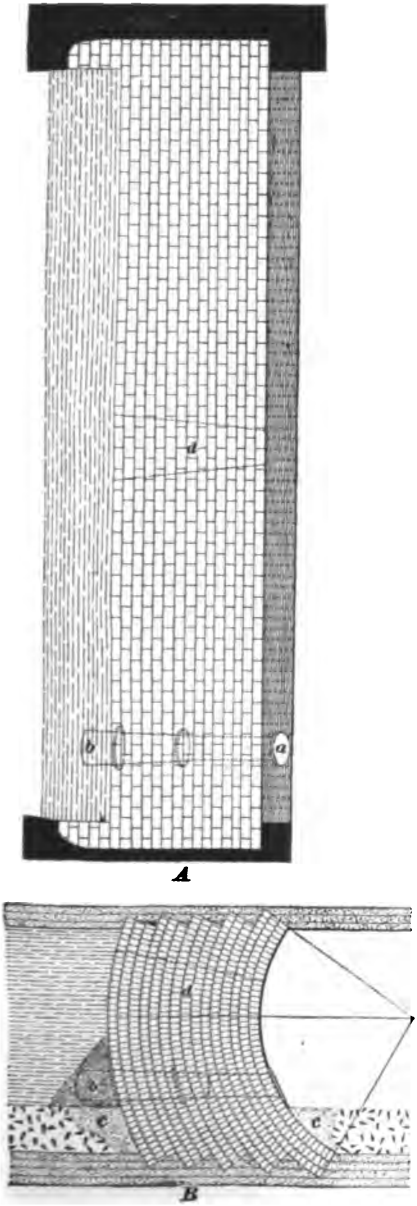


FIG. 548.

Therefore, the dam shown in Fig. 548 was built close to the break in the roof, so that no large quantity of water would be standing behind the dam. It was built of brick, 5 feet thick, laid in cement. Its length from pillar to pillar is 25 feet, arching from bottom to top. The pressure is nearly 100 pounds per square inch.

In Fig. 548, *a* shows the cast-iron pipe for the escape of water while the dam is being constructed; *b*, the tapered white pine plug turned to fit the pipe, and *d*, the manhole used by the workmen after having finished the dam from the inside and as an escape after driving the plug *b*. By reference to the figure, it will be seen that the soft stratum immediately under the coal was cut away and the brickwork dovetailed into the harder stratum, as it is into the top. Concrete *c* is placed at the front and back of the dam where the soft bottom has been taken up.

The proportions of the constituents of the mortar were: 1 barrel of cement, 2 barrels of sand, and ½ barrel of water. The joints were ¼ inch wide. The mortar used for brick or stone dams should be the best Portland cement, except where the dam is constructed to resist a comparatively small pressure.

It should be observed by the student that this dam is formed of separate cylindrical arches, each of which is dovetailed into the top and bottom; and built straight across the passageway, because it would be an expensive matter to arch such a wide dam longitudinally. In fact, it would not be necessary, unless extraordinary pressure must be resisted.

1710. The thickness of cylindrical or spherical dams to resist a given pressure may be approximately determined by the following formulas, by Prof. W. Steadman Aldis, which allow a safety factor of 10:

T = thickness in inches:

R = short radius in inches;

U = ultimate crushing strength in pounds per square inch, which is, for timber, 8,000; for stone, 6,000; and for brick, 2,500;

P = head of water in pounds per square inch.

Then, for a cylindrical dam,

$$T = R\left\{1 - \sqrt{1 - \frac{20\,P}{U}}\right\}. \qquad \textbf{(88.)}$$

For a spherical dam,

$$T = R\left\{1 - \sqrt[3]{1 - \frac{15\,P}{U}}\right\}. \qquad \textbf{(89.)}$$

These formulas give very small thicknesses for dams to resist comparatively slight pressures. In no case, when a water head of over 10 feet is to be resisted, is it good practice to make the dam less than 3 feet thick. For heavy pressures the formulas are safe, provided their results exceed 36 inches, after being multiplied by 2.

Example.—What should be the thickness of a cylindrical dam built of timber, having an external radius of 20 feet, under a head of 100 feet of water?

Solution.—$P = 100' \times .434$, pressure per square inch for each foot of height = 43.4 lb.

Substituting values for letters, we have

$$T = 20 \times 12\left(1 - \sqrt{1 - \frac{20 \times 43.4}{8,000}}\right) = 13.39 \text{ in.}$$

$20 \times 43.4 = 868$; $\frac{868}{8,000} = 0.1085$; $1 - 0.1085 = 0.8915$; $\sqrt{.8915} = .9442$; $1 - .9442 = .0558$, and $240 \times .0558 = 13.39$ in. Ans.

This result is theoretically correct, but as a thickness of 13.39 inches will give a comparatively small bearing surface for one wedge on another, the rule of making a wooden dam at least 3 feet thick should be applied here.

Example.—What should be the thickness of a spherical dam built of *brick*, having an external radius of 20 feet, under a head of 100 feet of water?

Solution.—Substituting the figures for the letters of the formula for spherical dams, we have

$$T = 20 \times 12\left(1 - \sqrt[3]{1 - \frac{15 \times 43.4}{2,500}}\right) = 22.968 \text{ in.}$$

$\frac{43.4 \times 15}{2,500} = 0.2604$; $1 - 0.2604 = .7396$; $\sqrt[3]{.7396} = .9043$; $1 - .9043 = .0957$, and $.0957 \times 240'' = 22.968$ in., say 23 in. Ans.

To prevent leakage in dams, the thickness, notwithstanding the safety factor of 10, should be doubled.

METHODS OF WORKING COAL MINES.

(PART 2.)

LONGWALL METHODS.

INTRODUCTION.

1711. When coal is found at a depth beyond 1,500 feet, it is unprofitable, if not impossible, to work it by the pillar and chamber or pillar and stall method, because the enormous weight will either crush the pillars or force them into the strata immediately above and below the seam, resulting in closing up the haulways entirely. In such cases a method known as **longwall** is used; this method, strictly speaking, means taking out all the coal in one operation, commencing usually near the opening and carrying the excavation towards the property limits. The passageways are maintained by walls built of rough material obtained from the floor or roof of the mine, or it may be taken into the mine from the surface.

A narrow space along the entire working face is kept open and advanced as the face advances, by supporting the superincumbent strata by filling in the space from which the coal has been removed with the refuse of the seam or material blasted from the top or bottom of the haulways. Wooden **nogs** and **chocks** are used to support the roof where waste material can not conveniently be obtained in sufficient quantities, or where it does not make good building material for the road sides. The nogs are built of logs piled two on two, to form a square pillar, and the chocks are similarly built, except that small pieces of hard wood 6″ × 6″ × 18″ are used instead of logs.

1712. The width of the space between the gob and coal face depends upon the nature of the top. In thin seams where the top is soft and brittle it may not be more than 3 feet, while in a seam 10 feet thick and having a good top it may be 8 or 10 feet wide, or more. The nature of the top in this way decides the number of roads necessary to mine the coal. If there is a good top, but few roads are required, as the car is taken along the face, which is approached by roads from 200 to 1,000 feet apart. But if the top is brittle, the space is necessarily too narrow for the car to be taken along the face, and, indeed, often too narrow for the men to work in conveniently. In such cases it is laborious to shovel the coal to the road-heads, which operation is productive of a good deal of slack. Therefore, roads under brittle top are seldom more than 16 yards apart, and frequently not more than 12 yards apart. A sled, sometimes called a buggy (a small box on sledge runners), is used to convey the coal to the road-head, so that the roads may be less numerous, but this method has a very limited practice in America.

1713. The longwall method of working, besides being the only recourse for the mining of seams found at great depths, is used also for thin seams at moderate depths for the purpose of securing exhaustive mining and a better marketable condition of the coal. The system is especially applicable to thin seams when they have a **following stone,** or stratum overlying the seam, and which falls as the coal is removed.

SHAFT PILLARS.

1714. In some coal fields no shaft pillars are left when longwall is employed in seams of moderate thickness. In such a case the coal is all mined out, and the gob carefully filled in with the refuse of the seam, material taken from the roof, or with stowing material taken into the mine. This work of stowing must be very carefully done, ramming being in some cases resorted to. In this way it is claimed that subsidence gradually takes place, until the gob is reduced to almost the compactness of the original strata, without

destroying the line of shaft. When this condition is reached, there is no danger at any future time of the shaft being destroyed by a creep. If a depth is reached at which narrow passages through the pillar can not be kept open, it is evident that a shaft pillar at such a depth is out of the question, regardless of the thickness of the seam.

There are places on record in North America where the slope openings can not be maintained at a depth of 600 feet in the solid coal, while there is but little trouble in maintaining them when the coal is all taken out, starting at a point above which the weight of the strata does not affect the pillar. Nevertheless, most longwall workings are now opened by leaving a shaft pillar of a suitable size, which will resist the weight of the superincumbent strata until the second break takes place over the excavation as it advances from the shaft. This will relieve the pillar of all weight except that due to the strata to be maintained intact for the preservation of the shaft. What was said in Part 1, Art. **1576,** regarding the size of shaft pillars is true here also.

THE WORKING FACE.

1715. Form of Working Face.—In longwall workings it is the aim to carry the face in the form of a straight line, a circle, an ellipse, or an arc of either of the two latter, depending upon the relative prominence of the cleats of the coal, the nature of the top and bottom, and the dip. The circumstances determining which of these forms will be suitable for any particular case will be made evident later.

1716. Fast Sides.—A weak top has a tendency to break along the line formed by the working faces, and if the line of faces is long this tendency to break in the roof becomes dangerous. To obviate this, the line is broken into steps and the places kept in advance of each succeeding one. The length between the steps may be regulated to any required distance, from 12 yards upwards. The great objections to fast sides are that the pressure destroys the coal on the corners, their cutting incurs an extra cost in the production, and the many crooks obstruct ventilation.

1717. Direction of Working Face.—The faces may advance :

1. Perpendicularly to the cleavage planes or **cleats,** or "on the face."

2. Parallel to the cleats, or "on the ends."

3. Obliquely, or at an angle of 45° with the cleats, or "half on."

4. Obliquely between the angles of 1° and 45° from the cleats, or "short horn."

5. Obliquely between the angles of 45° and 90° from the cleats, or "long horn."

It must not be supposed that it is a matter of indifference which of these directions should be adopted in any given case. It depends on the breaking down of the coal, the physical condition of the coal after it has been broken down, and, in some cases, where the cleat of the roof runs parallel with the cleat of the coal, the safety of the workmen. Therefore, it is very important that the circumstances of the case be considered when laying out the workings of a colliery.

1718. The object of all methods and expedients adopted in mining are to obtain the greatest quantity of coal, in the best condition. at the least cost. Since the direction of the face affects the physical condition of the coal, the labor of breaking it down, and the safety of the miner, it is obvious that it bears directly on the cost of production. Two of the principal aims are to reduce the amount of slack to a minimum and to reduce the amount of labor. These are frequently antagonistic, and when this is the case a middle course must be taken.

1719. By working a seam directly on the face the coal may be mined at a minimum price, while the waste or slack may be at the maximum by the weight breaking the coal off when the "backs" (cleats) are close together.

Slack (except in the best coking coals) is comparatively worthless; therefore, the profit must be made entirely from

the nut and lump coal. It is, therefore, apparent that it is better to mine the coal in a direction that will increase the ratio of lump, even if the cost of labor be increased.

1720. Coal divides readily along the planes of cleavage, known as cleats, and when some of these cleavage planes are but slightly developed, the coal offers great resistance, comparatively speaking, in a direction perpendicular to the cleat. As longwall workings advance, the roof bends along the line of wall faces and finally breaks, falling into the gob. Two forces are brought into action by this bending: the one which acts downwards tending to crush the coal, and to cause it to cleave parallel to the wall face on the side next the gob, which is unsupported; and the one which acts in a

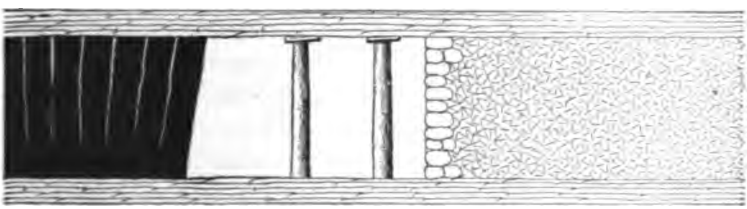


FIG. 549.

horizontal direction, being applied only at the upper surface of the seam, tends to divide the seam parallel to the face, in exceedingly thin scales. Suppose that the seam divides vertically, and in a direction parallel to the face, into slabs of a definite thickness. The horizontal force applied to the upper edge of each of these slabs tends to rotate it upon its lower edge as a center, by which motion the upper edge will be advanced towards the unsupported side, and the wall face will be inclined as shown in Fig. 549. But, as the force acts more intensely as the wall face is approached, the slabs from the face inwards will be less and less inclined, i. e., they will have been separated by a less distance towards the upper edges. Coal is never perfectly homogeneous, and the cleaving force is never applied with the same intensity at every point. Therefore, the seam has a tendency to break up, under the action of the descending roof, into slabs of

irregular thickness, or it may be into prisms of irregular dimensions, in consequence of an unequal resistance. The effects are shown in Fig. 550.

It will be seen in Fig. 550 that the pressure of the descend-

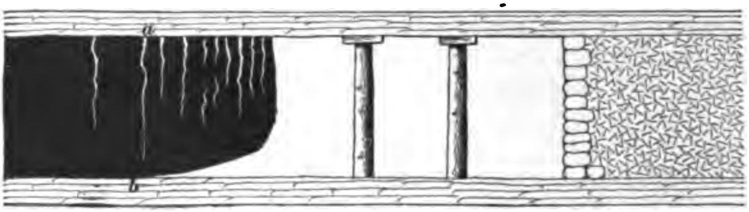


FIG. 550.

ing roof has split up the seam to a distance of about 4 feet from the face, and that the cracks so caused increase in number and in width towards the face.

1721. It seems evident that the degree to which the coal will be broken under such conditions as these will depend upon:

1. The strength of the roof, which may bend and drop slowly, or break off short.

2. The nature of the roof, which may consist of hard or soft rock.

3. The pitch of the roof, which largely determines the pressure at the wall face.

4. The direction of the workings, whether to the rise or to the dip.

5. The strength of the coal.

6. The direction of the cleats relative to the wall face.

1722. Now, consider the last circumstance, which involves the whole of the foregoing. Suppose the face in Fig. 550 is parallel to the cleats, i. e., that the faces are advancing across the cleats. The direction in which the pressure tends to cleave the coal coincides with the face cleats, and it is, therefore, clear that the cleaving force will act under the most favorable conditions. If the coal be strong, a few extensive lines of fracture may be caused

which will greatly facilitate the getting of the coal by breaking it up into large blocks or slabs, thereby saving much labor in bringing it down. The mass can be subsequently broken up into blocks capable of being handled.

1723. When the face is undercut, as shown in Fig. 550, the pressure of the roof plus the weight of unsupported coal tends to produce a fracture along the line *a b*, and if *a b* be a plane of cleavage, the conditions will be most favorable to the action of the pressure. The foregoing shows that advancing the faces across the principal cleats reduces labor to a minimum, thereby satisfying the conditions of least cost.

But the physical condition of the coal is a consideration of equal importance; for, if the cheaper labor is secured at the cost of an increased amount of slack, the result may really be a loss instead of a gain, when the production is put upon the market.

1724. If the coal be of a weak and tender character, there will be numerous short lines traversing the mass vertically and horizontally, and dividing it into thin slabs and small prisms, instead of the long slabs and few lines of fracture as in the former case. When the "web," or mass, falls, these slabs and prisms are very easily broken across, and the same liability to easy fracture exists during the operation of breaking up the web, or mass, and loading it into cars. A considerable part of the coal is ground small by the roof pressure, especially along the top of the face, where the greatest pressure exists. The final result is a very large amount of slack for longwall mining.

The ease with which the coal falls is a source of danger, which must be provided against by employing sprags to support the "web" while the coal is being undercut. It is evident, under these conditions, that the advantages gained by working "face on" are nullified by the increased percentage of slack.

1725. If the faces are advancing on the end of the coal, or "end on," the pressure of the roof tends to cleave the coal perpendicularly to the cleat or principal cleavage plane,

and the resulting condition is most unfavorable to the action of the cleaving forces. The "end on" plan is the best possible condition to resist the cleaving and crushing action of the pressure due to the descent of the roof. Therefore, the coal will be obtained in larger blocks, and the waste or slack will be reduced to a minimum. As an offset against this improvement in the physical condition of the coal, the labor will cost more. The likelihood is that the better price for the whole production will be greater than the extra price paid for mining.

1726. "Half on" is a method midway between those just discussed, and "long horn" and "short horn" are simply variations between "face on" and "half on," and "half on" and "end on." Any one of these methods may be made necessary by the dip of the seam, the texture of the coal, etc. "End on," for instance, may be advantageous in a moderately strong seam where the pressure is great.

1727. The dip is another important consideration in this same connection, which, irrespective of the other conditions, may determine the direction in which the faces shall be driven. The manner in which the dip most frequently determines the direction is by affecting the mode of conveying the coal to the shaft. It is plain to all that it is of the highest importance to take advantage of the force of gravity. By arranging the face of workings and line of haulage roads in such a manner that the coal, from the moment it breaks from the seam, will gravitate continually to the shaft bottom, an immense amount of labor will be saved. Even when an inside slope is driven from the shaft bottom, to work the coal to the dip, the levels and temporary roads are laid out to take advantage of the force of gravity.

1728. The inclined plane delivers coal at the smallest cost when it is practicable. A slant road is sometimes used instead of an incline on the full pitch, so that mule haulage can be used. Conditions seldom justify the use of a slant

where an incline could be used, because a slant is longer than an incline to reach the same coal, and in pitching seams the *buildings*, or packs, are harder to keep in repair.

The directions of dip and cleat have no fixed relation to each other; sometimes they are parallel, in other seams they are at right angles to each other, and in different districts they may vary from each other through all the points of the compass.

1729. There are many difficulties in the application of longwall to seams exceeding a dip of 12°, but the chief ones are found to be:

1. The tendency of the roof to slip and sink back away from the face, thus taking the desired pressure from the coal. In longwall working one of the great objects aimed at is so to control and regulate the pressure of the roof strata as to keep a *continuous* or *traveling* weight upon the

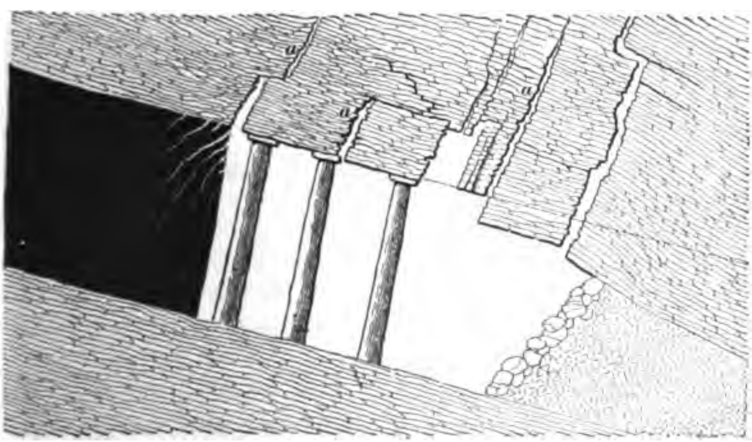


FIG. 551.

coal, thus reducing the labor of mining, and breaking down the coal without the necessity of much, if any, blasting, care being taken not to crush the coal. In flatter seams this is a comparatively easy matter, as with moderate care it is not difficult to control the pressure of the roof with packs and timbering. But, as the inclination increases, there

is considerable difficulty in preventing the broken masses of the roof gravitating away from the coal in the direction of the dip of the measures, and either sinking in front of the face line or bringing excessive pressure to bear on the edges of the coal face, thus crushing the coal. A good example of this is given in Fig. 551, which shows an actual condition that existed in the Staffordshire (England) district where the coal was badly crushed. The breaks *a* average from 50° to 60° from the horizontal. The roof has slipped down hill, owing to careless packing, and throws excessive pressure on the edge of the coal, which becomes seriously crushed.

Fig. 552 shows the coal strong and firm and broken off at the back of the mining. In this case the roof has broken

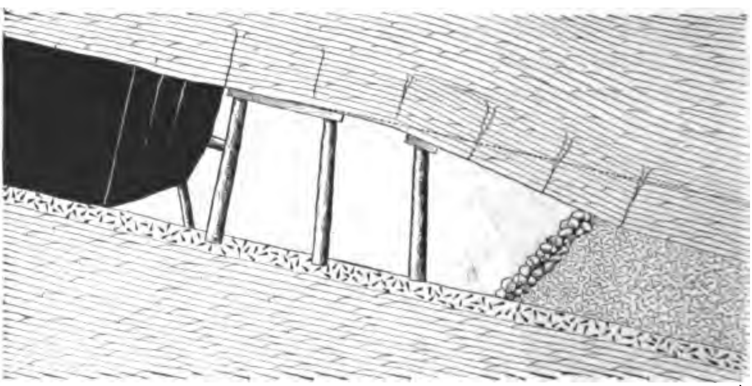


FIG. 552.

off properly, relieving the coal face of any unnecessary weight, for while the roof is broken above the face of the coal, that portion of it which is supported by the props still keeps the roof above the mining from sliding forwards and crushing the coal, as is done in the former case.

2. The disturbance of the packs, etc., on the high side of the levels or gangways, caused by the slipping of the roof. This is shown in Fig. 553, in which the pack *w*, originally 4 feet high, has been pressed down to 3 feet on the side of the level or gangway, while on the rise side of the same pack, at the point *r*, it is only 18 inches thick, showing a settling

of 12 inches in the first and 30 inches in the second instance. This is partly due to the extra strength of the support, due

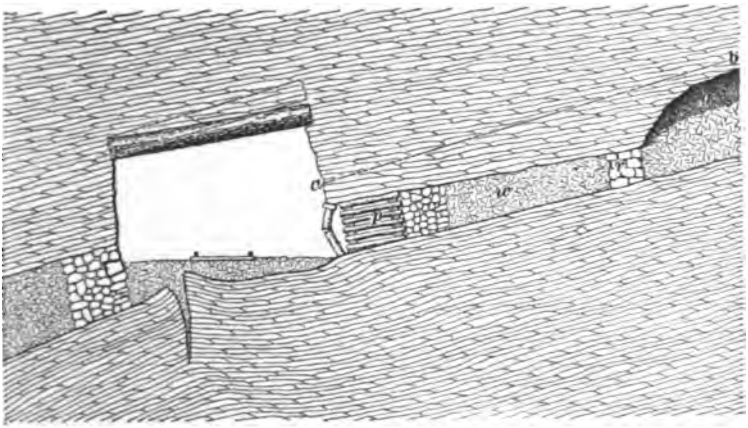


FIG. 558.

to the wooden chock *p* on the roadside, and also to some extent to the area of unsupported roof in the waste or gob *g* above, between the rise side of the pack and the first break of the face line. The dotted line *a b* shows the original position of the roof.

The immediate effect of this unequal sinking is to reduce the original inclination of the roof in and immediately above the level road, and it naturally follows that the tendency to slip will be greatly reduced. It has been found that in roads where the original inclination of the roof was 16° or 17°, the angle with the horizontal is reduced to 10° in a very short time after the coal has been worked out.

1730. *Systematic mining* and *regular progressive advance of the working faces* are essential points in working by the longwall systems.

Since the line of "break" is about at right angles to the seam, the line of greatest pressure is clearly fixed if the work is properly and systematically carried out. In connection with the line of "break," in pitching seams, the "pull" due to gravitation down hill must also be considered.

It will be seen that, in order to throw the pressure forward, in advance of the face line, it is necessary to support the roof in the same manner that the face of the coal is spragged while it is being mined, but this can only be done to a limited extent. If an attempt be made to support too great an area of roof, the timbers will be broken and the prime object frustrated. Therefore, timbering should be kept within the smallest possible limit, so that, without using an excessive quantity of timber, the roof under which the miner works is kept well supported, and the roof a short distance back is allowed to fall and thus relieve the timbers from excessive pressure.

1731. At the working faces the props should be carefully set in line so as to assist in breaking the roof parallel to the general face line. The best results are obtained by setting the rows of props in exact line at right angles to the face line, so that each prop in the *several rows used* will be in the best position to help the next, which would not be the case if the props were **staggered** or set without order. This system of staggering the props is in use in many longwall mines, but it is hard to show the advantage derived from it. The row of props close to the face is of great importance in preventing the roof from cutting, or sinking in front of the coal. The breadth of roof supported by props varies from 3 to 8 or 10 feet, as stated before, and the timber is only left in the 8 or 10-foot breadth for a very short time after the coal is broken down. When the coal is removed, the third row of props should be drawn and set between the other two rows, in the space which was the car road, if the car was taken along the face.

1732. The face packing in all longwall work is a very important matter, but in pitching seams it is doubly so. As soon as the coal is removed, the packs must be carried forwards as near to the face as they can be built without obstructing the ventilation. It is very necessary that they should be kept in a continuous line from the side of the level forwards through the work. Where, from special circumstances, it is found necessary to start new packs in the gob

during the progress of the work, it will be found advisable to build good, solid chocks as a support to the first few yards of the building.

Packs must be carefully built of the strongest available material, and each section of the packing should be carried square and solid up to the roof and securely wedged.

1733. In pitching seams, when faces cross the pitch diagonally and the roads are at right angles to the faces, the dip and the tendency to slip are reduced, and a certain amount of lateral pressure is carried on to the coal. Care must be taken that the lower places have a certain relative amount of **lead,** or, in other words, be further advanced (not necessarily a fast side), so that the break from the next stall above will not travel too directly on the line of the working face below as it advances, but will be steadied by the packwalls.

1734. The size of the packs and gobs is regulated by the nature of the roof, care being taken that they are sufficiently wide to allow the roof to break down easily. If there is not enough refuse in the seam to completely fill the gobs, wood chocks are used, which are moved forwards in the same manner as the props. If these chocks were left in, they would throw the weight of the strata above on the coal face, crushing the coal, and on the packwalls, to their injury.

The proper management of the roof or top weight in working *successful* longwall is one of the chief features of the system. The great point is to so regulate or control the pressure on the face, by means of props and chocks, that it shall be neither more nor less than enough to bring down or greatly assist the miner in mining and bringing down the **web,** if the coal is mined in the bottom.

MINING, HOLING, OR BEARING IN.

1735. Too much importance can not be bestowed upon this part of longwall work. Whenever practicable, the mining, or undercutting, should be made in the clay or mining dirt under the coal; but if this can not be done, it should be made in the bottom layers of the seam itself. Sometimes,

however, a more suitable place occurs on top of the seam, or it may be near the middle; but, wherever the best place exists, the miner will, if a skilful pickman, take every advantage of the natural structure of the bed he is mining in, as well as the weighting action upon the coal face, which helps to soften or break up the mining dirt as the operation of holing goes on. The experienced miner, in undercutting, takes off what is sometimes called a "skin" (6 to 12 inches in depth) as he goes along the face. This enables him to do the undercutting with very much less labor than if he were to cut the full depth under without giving the pressure time to make itself felt at a deeper distance from the face of the mining.

1736. A seam of coal should, if practicable, be mined or undercut as deep as it is high, and the face of the mining should be very low, so that as little slack will be made and as little labor expended on the work as possible. In thin seams the skilful miner, on account of his ability to mine deep in a holing of 6 inches high at the front, will produce from this cause alone 5 to 10 per cent. more lump coal than the inexperienced miner. Longwall mining will produce a greater yield per acre than the pillar method, and will also produce from 5 to 15 per cent. more lump coal, ton per ton, than the pillar method.

ORDER OF WORKING CONTIGUOUS SEAMS.

1737. The order of working contiguous seams does not admit of a general determination, as in the case of pillar work. In Fifeshire, Scotland, in many cases where several seams are worked simultaneously, the lower one is kept in advance of each succeeding seam above. In some other parts of Great Britain, where there are 105 feet between the two seams, the best results are secured when the seams are worked nearly together. In other cases, where the seams are from 30 to 40 feet apart, it is found best to work the lowest seam first and the upper seam long after; while, again, in the case of three seams having 36 and 66 feet respectively between them, it is considered best to work the seams in

the descending order, the face of the upper seam being kept not less than 30 feet in advance of the face of the lower seam. Still again, in the case of three seams parted by 72 and 75 feet respectively, it is considered best to work the seams in ascending order, and, if possible, in conveniently small districts, so that the lower seam may be completely extracted before work is begun upon the upper seam. When this can not be arranged and the seams have to be worked simultaneously, it is best to keep the face of the lower seam 120 to 150 feet in advance.

1738. The order in which contiguous seams are worked may affect both the roof and the texture of the coal. In gaseous seams the pressure exerted on the face of the coal greatly assists its extraction. The escape of the gas from the coal through the breaks or cracks in the intervening strata, which are caused by the removal of contiguous seams, either above or below it, and the disturbance thereby produced in the equilibrium of pressure in the strata, make the coal tougher and harder to extract. The disturbing elements between two contiguous seams are nearly at right angles to the inclination.

1739. The order of working contiguous seams depends not only on the ease of extraction, but on the market value of the coal as well. If the roof be injured, the result is greater insecurity, which will cause accidents if not provided against. This increased insecurity, in many cases, can be met by increased care in timbering, so that the consideration of the effect on the roof is in most cases subordinate to the effect on the coal. Where the effect is to harden the coal, the price paid the miner per ton is greater, and in the case of a soft coal the percentage of lump coal is increased.

If the increased selling price is greater than the increased cost of producing the coal, which is the case with many soft coals, the hardening is profitable. Coals which are already hard are made less profitable by a further hardening.

1740. The following points must be carefully considered when dealing with the working of contiguous seams:

(1) Distance between the seams; (2) thickness of the seams; (3) whether the gob is tightly packed or not; (4) nature of the roof and floor; (5) the inclination of the seam; (6) the depth from the surface; (7) the rate at which the working faces advance.

SYSTEMS OF LONGWALL.

RELATIVE ADVANTAGES OF SYSTEMS.

1741. Longwall, like the pillar methods, has many variations; it may, however, be divided into two systems as follows:

1. Longwall advancing.
2. Longwall retreating.

These terms are self-explanatory. **Longwall advancing** simply means that the operations are begun at the opening and carried forwards towards the property limits, and **longwall retreating** means that the working face is formed at the boundary of the territory to be developed by driving main haulways from the opening, and then carrying the working face backwards towards the opening or shaft bottom.

1742. If the conditions for longwall working exist, and the operator can stand the early outlay for yardage which necessarily must be paid for the narrow work, then the following points may be considered in favor of *longwall retreating*, or *longwall withdrawing*, as it is sometimes called:

1. The haulage roads, airways, waterway, traveling way, etc., will be more cheaply maintained, of better dimensions, and easier to travel.

2. The risk of detrimental gob-fires will be reduced.

3. Seams high enough for mule haulage will require no taking down of top, so that the miners will be occupied in coal getting only.

4. There will be less risk of accident from falls of roof, because all work would go on beneath a solid top.

5. The coal field will be actually proved before 10 per cent. of the coal is taken out.

6. The (sometimes) disastrous effects of weight upon the gob-road packs and the working faces, due to having to leave solid pillars of coal under important surface buildings, etc., are better provided for, and are hardly felt when working on the *retreating* plan, because the crush or squeeze on the ribs and the top weight thrown upon the gob do not in any way affect the roads in the solid.

7. Main haulways liable to be blocked by extensive falls of top in gob-roads have, in the withdrawing system, every chance of being free from such dangerous and troublesome obstructions.

8. Greater ability to shut off fire, or to allow a portion of the working face to remain idle for a while without much liability to cave or cause trouble. In gob-road mining, the roof is usually so broken up back of the faces that to make a place air-tight is a matter of great difficulty.

1743. In some cases it is necessary to consider not only the strata directly on the top of the coal, but the strata higher up. Many times there is a frail bench on top of the coal, while the strata above it may be exceedingly strong sandstone or limestone, which, notwithstanding the seemingly nice settlement of the top, may be hanging over a large area and exerting a pressure both on the coal face and road packs, in such a way that it may be hard to contend with.

LONGWALL ADVANCING.

1744. In the examples of longwall working, the ventilation is shown by arrows in all plans except those which merely show a very limited portion of a mine. In the latter case it can not be definitely shown, because it is impossible to adopt an arbitrary direction for inflowing and return currents. The question of ventilation in longwall work is a

comparatively simple one, and many variations, depending upon local conditions, may be made.

1745. Fig. 554 shows the plan of longwall operation where the top is brittle, the pitch is from 10° to 60°,

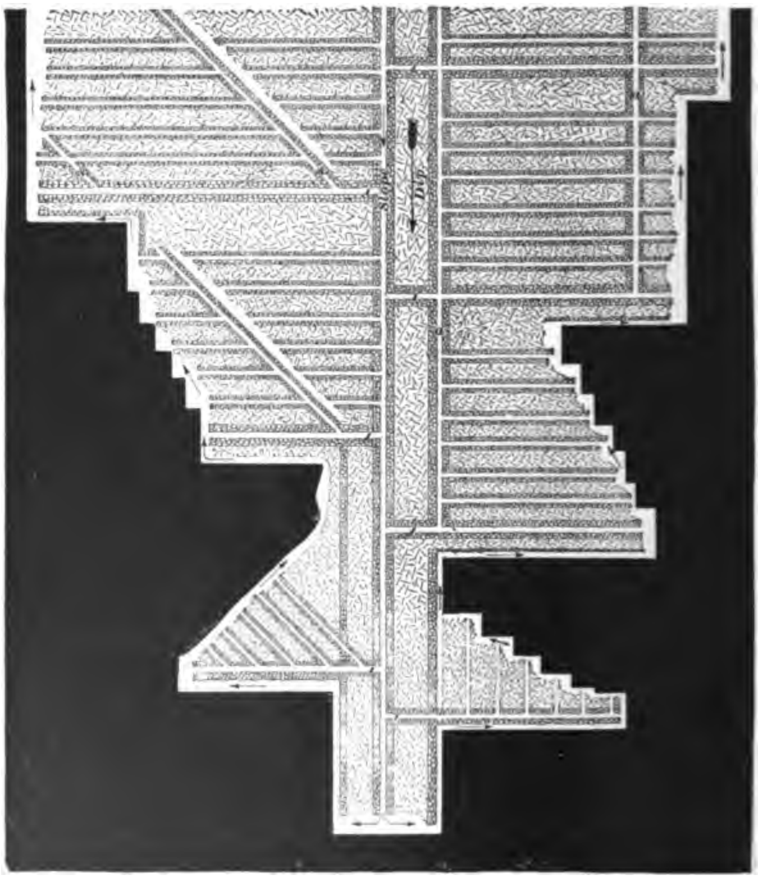


FIG. 554.

the coal does not exceed 3 feet in thickness, and there is sufficient waste from the seam and from opening up the roadways to build the packs, and, to a reasonable extent, to fill the gob.

The upper division on the left of the figure shows a plan

of operation when the pitch is such that a slope or dip can be driven on a pitch of about 5°, over which the coal is lowered to the level below, which in its turn connects with the slope or heading leading to the shaft. The line of face is parallel with the dip, regardless of the line of cleat.

The second division shows the same plan, with the exception that the faces are advanced in steps, principally for the reason already given in Art. **1716.**

The third division on the left shows a plan of working employed where the pitch is such that the cars may be taken to the face, where it is desirable to work the coal "half on," when the cleavage planes are parallel with the dip, or where there is no marked cleavage.

The upper division on the right-hand side shows the plan sometimes employed where the inclination is from 15° to [illegible]. The faces, irrespective of the line of cleavage, are driven at right angles to the dip and parallel with the level, the coal being lowered to the level by self-acting balance inclines *a*. A chute is sometimes used instead of the balance incline.

The middle division on the right-hand side shows the same arrangement, except that the faces are advanced in steps, for reasons already given.

The third division on the right-hand side shows a manner of mining steep seams. The dip may be such that the coal is delivered by chutes or self-acting balance inclines operating in each road, or by a self-acting (not balance) incline in two roads, the loaded car going down the one road taking the empty car up the other. In the latter case there is no step between the two roads, the step being between each pair of roads.

1746. Fig. 555 shows two methods of circular longwall, one showing the walls, or faces, in steps (shown by dotted lines), and the other showing the wall in a continuous face. The downcast shaft *d*, the upcast shaft *u*, and the stables *h*, *h* are all formed in the shaft pillar, which is rectangular in shape. This plan, with but few modifications, is practised in parts of the central and western coal fields of the United States, as well as in other countries. It is a good method

for thin seams with a brittle or moderately solid top. It is necessary that all places, except roadways and a narrow space along the face, should be filled close to the roof with stowed dirt and proper packwalls. It is maintained by some engineers that the packwalls should incline slightly inwards to the middle of the pack, so that when the weight comes on

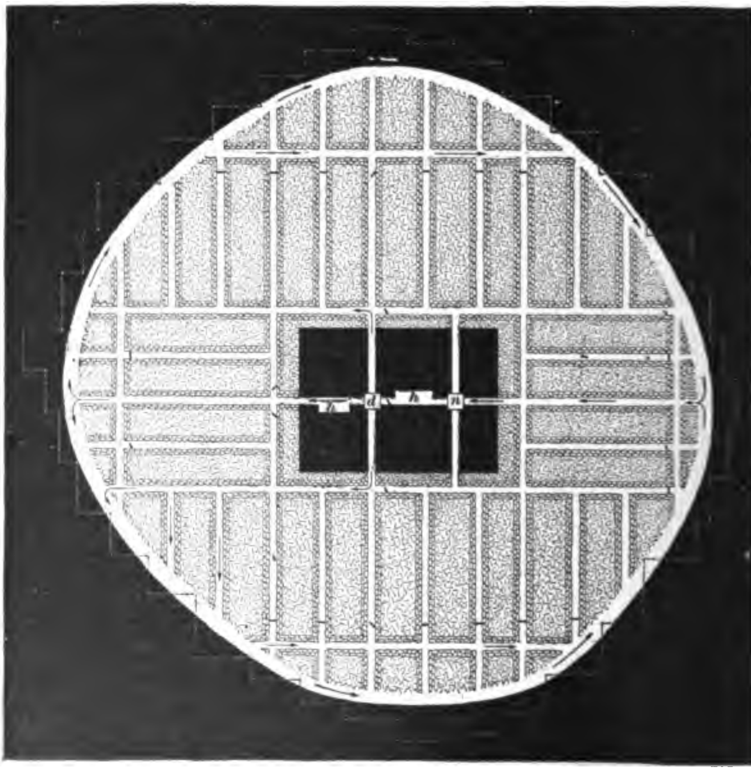


FIG. 555.

them they will not bulge out in the center. In almost all longwall work in thin seams, the height of the main roads must be maintained, after the roof has settled, by taking down top or blowing up bottom. In this case, the roadways are at first only of such a height as will give the necessary material for stowing the waste and building the packwalls.

The roof will settle in roadways from $\frac{1}{3}$ to $\frac{1}{2}$, or more, of the thickness of the seam, depending on the proportion of the gobbing. The work in this figure is laid out with a view of having the same number of working faces in each direction, so that the haulage roads will be equally divided, thereby facilitating the delivery of the output to the shaft bottom. Canvas doors are used until the top has settled, when overcasts and doors of the regular pattern are used. This system is well adapted to shallow depths, where numerous shafts can be sunk cheaper than long roads can be fitted up and maintained for mechanical haulage.

1747. Fig. 556 shows the Missouri plan of longwall operations in seams with a strong and flexible roof, where the seam is from 20 to 22 inches thick. From the bottom of the shaft four entries are driven in the seam, at right angles to each other, for a distance of from 20 to 50 feet. This distance depends on the character and strength of the roof, the depth of the coal beneath the surface, the nature of the underlying clay, and also upon the anticipated period of operation of the shaft. From the ends of these roads cross-cuts are then driven, connecting them with each other. From the exterior sides of these cross-cuts the coal is now mined radially from the shaft, the main entries advancing with the face and being kept open by packwalls and gobbing. This process continues until the face has advanced about 800 feet, and until the distance between the ends of each two adjacent entries is about 1,200 feet. When this stage is reached, the face is still pushed forwards in the same direction as before, but, instead of one entry being left open and packwalls built, two are now left, which radiate from the main entry, one on the right and one on the left, each at an angle of 45° with the original direction of the main entry. In the angle between these two new entries a triangular packwall is built, as a permanent pillar, and beyond it the mining of the coal continues as before. When this has proceeded to such a distance that the haul along the face of the coal to the entries again becomes excessive,

bifurcation (dividing into two prongs or forks) of the entries is again resorted to.

The process continues until the limits of the property are reached, unless the coal is at such a shallow depth that it is more economical to sink new shafts than to have a long underground haul.

Part of the shaft *s* is used as the downcast airway, and as

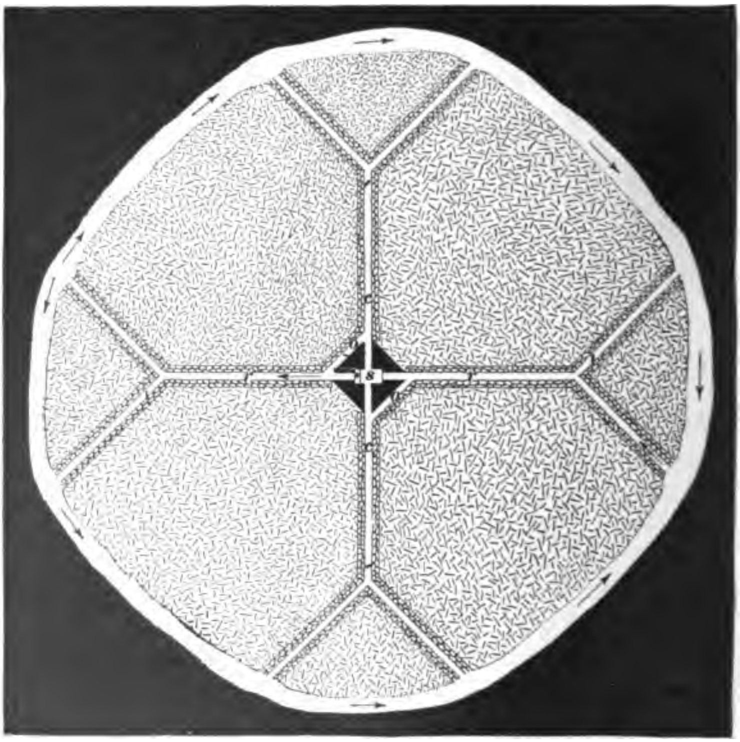


FIG. 556.

the caging is usually done on two opposite sides it is necessary to leave passages *o* on two sides of the shaft pillar in order that the cars may be taken from the roads *r* to the roads *c*, where they will be in the proper position for caging.

Of course it is understood that the track is laid along the

working face between the entries and is moved forwards as the coal face advances.

The coal is undercut to a depth equal to its height along the whole face, and is wedged down or pressed down by the weight of the superincumbent strata. A certain length of face is assigned to each miner. The general conditions are

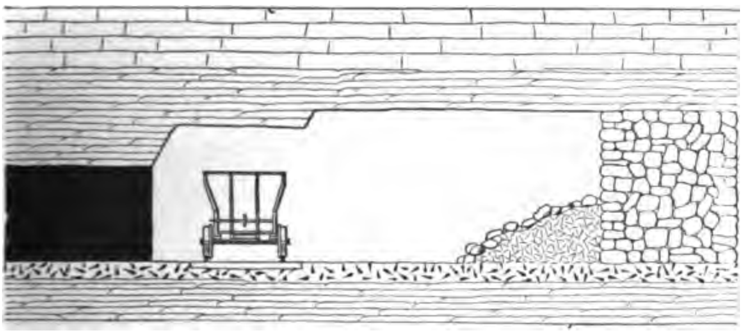


FIG. 557.

illustrated in Fig. 557, which is a section of the seam parallel with one of the packwalls.

As the coal itself is not high enough for passageways, and because material is needed for packwalls, the floor is taken up and the roof is taken down. The main roads vary from 4 feet high by 4 feet wide to 8 feet high by 12 feet wide, depending mostly on the nature of the top. If the roof is of solid limestone, sandstone, or even a strong slate, the road may be almost any width desired. In the roads which are only used temporarily the height is from 3 to 4 feet.

The method of supporting the roof is shown in Fig. 558.

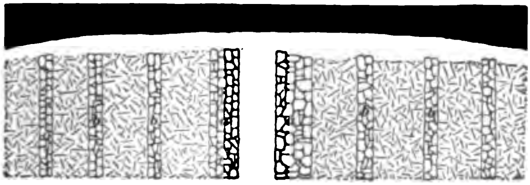


FIG. 558.

One heavy and well-built packwall *a* is carried along by the

miner on each side of the entries, and between these continuous pillars, less carefully packed walls *b* are carried along at right angles to the face as the work advances. These pillars are built of the heavier and larger blocks of waste material, and in between them the smaller and loose material is shoveled. The distance between the pillars is about 6 feet, and the smaller pillars are themselves about 2 feet wide and are tightly wedged to the roof.

1748. Fig. 559 shows a method of longwall pretty much the same as shown in Fig. 555, and much in practice in the

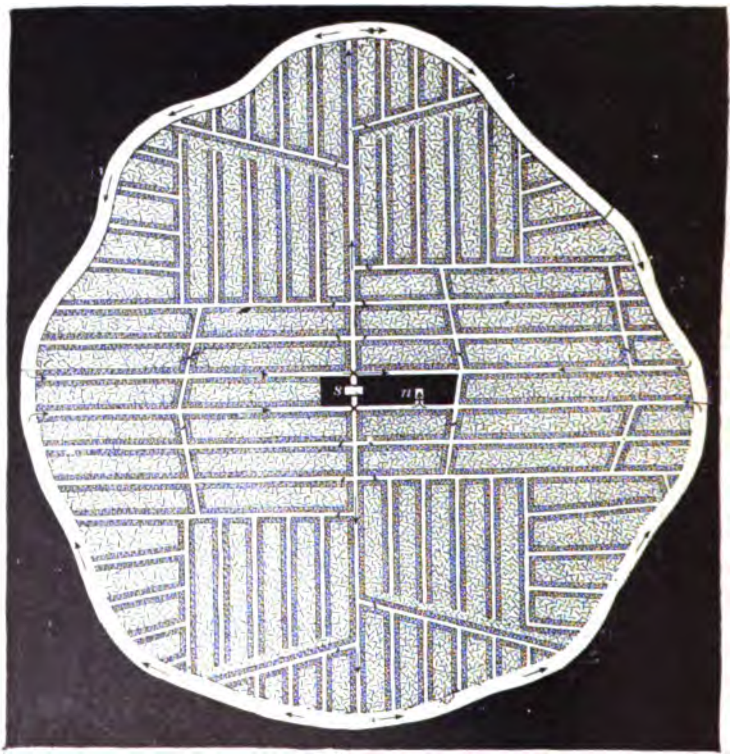


Fig. 559.

central and western coal fields of the United States. It is considered a good plan for low flat seams having a weak and

brittle top. In this plan so much space can not be maintained between the face of the coal and the packs as in Fig. 556. The coal is removed directly through numerous roads which connect with one of the principal entries. From the foot of the shaft *s* entries are driven in opposite directions. As soon as sufficient length of face is exposed for mining operations to proceed, the coal is attacked on both sides of the entry along the whole length. As the face advances, the waste material or gob is thrown behind, and at the same time roads are made with packwalls on both sides, at intervals of about 40 feet and at right angles to the main entry. Between two passages or roads, along the main entry, walls of packing are carefully built. The interval between two such roads is known as a "room," and is generally operated by one miner. A careful inspection of the figure will make the system clear to the student. At Leavenworth, Kansas, the dimensions of the main roads are 5 feet wide at the base, 4 feet wide at the top, and 6 feet high, the coal being 22 inches thick.

In this case, packwalls are carried along the entry sides, and on each side of the room road props are placed.

It is the practice, sometimes, to leave a small pillar of coal around the hoisting shaft *s* and sink the air shaft *u* in the gob. When this is done the air shaft is supported at the bottom by carefully built packwalls and stowage. Frequently, after the mine has been fairly developed, it will be found that more efficient ventilation can be obtained by sinking a shallow shaft some distance away from the hoisting shaft, in which case the new shaft will almost invariably be sunk in the gob. Otherwise, it is generally conceded best to leave a pillar of coal to support the shaft, because there is less liability of destroying its alinement through neglect or carelessness of any kind.

1749. Fig. 560 shows a plan of longwall work suitable for seams at great depths, ranging from 2 to 9 feet thick, of almost any texture, and with slight modifications for almost all kinds of top, although best results are obtained when the top is not very weak, and the dip ranges from 14° to 20°.

After the preliminary headings necessary for shaft pillars, ventilation, and drainage have been made, sufficient coal is worked out to allow first packwalls to be built, and from this point the face line is maintained nearly at right angles with the full dip. Two lines of track are laid to facilitate the loading, and in the case of the thinner seams, a slant to

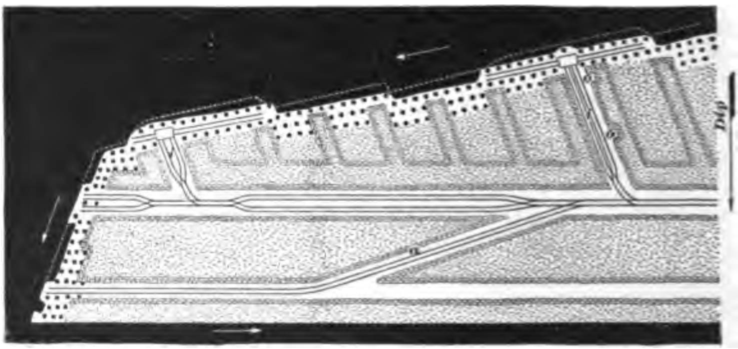


FIG. 560.

be worked by a mule is packed in as shown at *a*. In the case of the thicker seams the road *a* is not driven, and a hand winch is used to raise the coal from the dip side of the level to the level road at the face.

Special attention must be paid to the building of the first packwalls, as it is found that when the roof cuts off at the edge of the solid coal in the level, there is usually more subsidence than in the ordinary working.

1750. The first packwalls in the thinner seams may be built with débris brought from other parts of the mine or with material taken from the top or bottom of the roads in the solid. As soon as a sufficient length has been built, taking down top in the level is commenced. About 5 feet of roof is taken down in a seam 4 feet thick, care being taken not to take it down in advance of the packs, in order that the top rock will not be shattered over the position of the packwalls. Excepting where the workings are disturbed by subsequent operations, in overlying or underlying seams, very little further work is required in the main road unless

it is the taking down of a small thickness of roof, fractured by the blasting in the first operation.

Chocks, or wooden packs, are built 3 feet square, on the high side of the road, at intervals of five yards. The pack-walls throughout are built in sections of 4 to 5 feet in length, and crosswalls at right angles to the roadside are thus formed, which are a most important factor in securing the sides of the level. Offsets or manholes *o* are built in the side of the inclined roads to afford safety to the men while traveling therein.

In the case of thicker seams, that is about 7 feet thick, no ripping or taking down of top is done in the forming of the levels, and the whole of the packing must be made with the débris brought from other parts. And, as packs 7 feet high are not sufficiently stable as a rule for the rise side, it is found advisable to leave from 2½ to 3 feet of coal over the pack; this allows the necessary amount of subsidence to take place.

As soon as possible a temporary, self-acting incline *i* is put to work; and, for reasons which will be stated later, it is necessary to work the face to a certain extent concurrently with the opening out of the levels. It is not, however, advisable to carry on the regular working of the coal until a sufficient length of face has been opened out, because it will be difficult to keep the continuous line and direction required in order to work the system to the best advantage.

1751. The length of the working face varies with the thickness of the coal, the rule followed being that sufficient length of face is given each set of miners to allow a web (a mining) of coal to be taken out every week, or thereabout. The men work in sets of 6 or 8, two being loaders. Starting at the "road-end," or "road-head," the coal is taken down in one direction, and as soon as sufficient length of face is stripped, mining, or holing, is recommenced. There is practically no blasting of the coal, as it is found that where the packing and timbering is properly done the coal is broken at the back of the mining by the weight of the super-

incumbent strata. The dotted line shows the form of the face when the rear row of props will be advanced.

1752. As was mentioned before, packwalls on the high side of a roadway, and especially levels, are in a position where the tendency of the broken roof to slip downwards is first felt; and, unless proper precautions are taken to prevent that movement, they are likely to be pushed out. The essential points to be considered in this respect are:

1. That a sufficient breadth of coal is taken out below the side of the level, and the space thus made well packed.

2. That as the line of coal face progresses, steps are taken to continue the high side working as soon as possible.

3. That the high side packwall is so built that the pressure of the roof is met by greater resistance on the side of the level than on the portion of the same packwall nearest the working face.

1753. In deciding what breadth of coal should be worked on the lower side of the level, it is necessary to be guided largely by the direction of the first breaks in the roof, both on the rise side and the dip side of the opening out places. It is generally found that the direction of these first breaks varies considerably from the direction of the main break. The reason that it is necessary to consider the direction of the first break rather than the main break is because the fracture of the roof takes place soon after the packwall is built, and, therefore, any general pressure due to a uniform subsidence has taken place. The packing, however carefully built, is not in condition to meet sudden or violent disturbance.

1754. Fig. 561, which is a section of a longwall working having two parallel levels, is taken to illustrate the advantages of taking out a sufficient breadth of coal from both sides of a level. Suppose the coal was taken out below the level *r* to the point *c* and to the point *n* above, then the directions of the first breaks will be *c a* and *a b*, leaving no lateral support to the mass *a b f* when the top is taken down

in the level. This mass then has a tendency to slip down hill. It will also be noticed, by referring to the figure, that slipping will more readily take place if a sufficient breadth of coal were not worked out on the high side of the packwall, and if the first break should take place in the line *g h*.

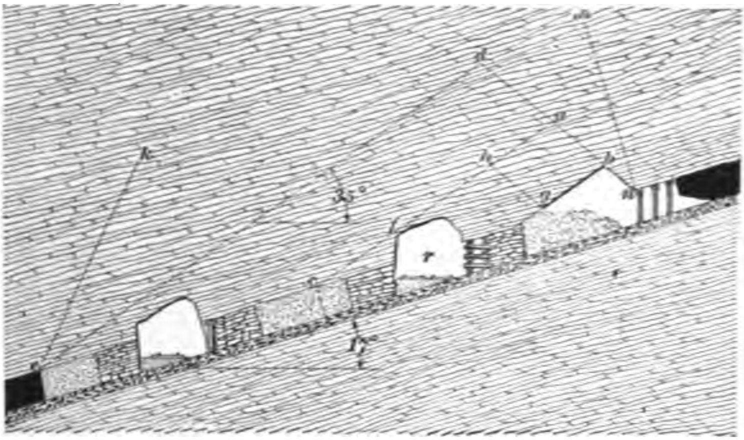


FIG. 561.

When sufficient breadth of coal is taken out on both sides of the roadway to cause the break to take the lines *b d*, *d c*, there is sufficient lateral support left in the loosened mass of roof *b d c* to prevent the downhill slipping, and at the same time the greater weight of that portion directly overlying the high side packing tends to exert a directly vertical pressure. The lines *e d* and *d b* show the direction of the first breaks, while the lines *c k* and *n m* show the direction of the main breaks.

1755. Fig. 562 shows a method of longwall which is largely practised in low seams, in which the regular mine car can not be taken along the coal face. The roadways *r* are turned off the heading or haulway *h* at intervals of about 30 yards, and when they are driven up 10 yards, lifts of 8 or 10 yards are turned off to the right and left and driven parallel to the heading for 15 yards, or one-half the distance between the roadways. Two men at a time work in each

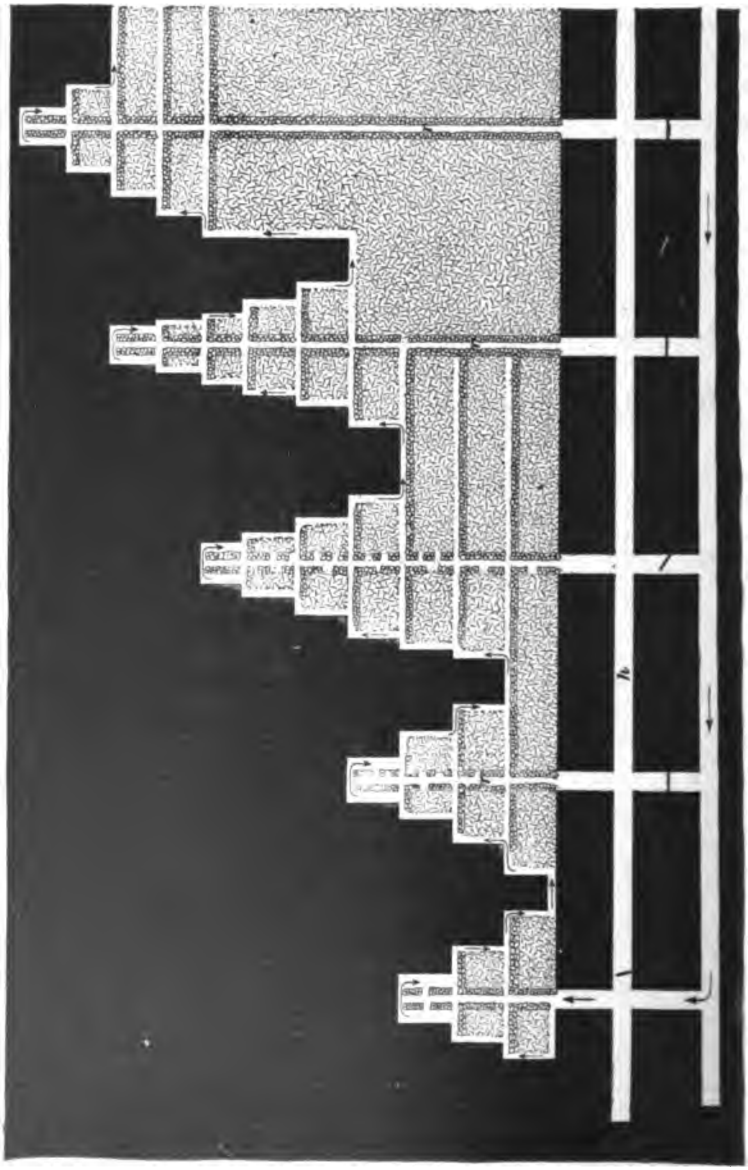


FIG. 13.

lift. Sometimes the roadways are turned off at intervals of only 10 or 12 yards, in which case the coal is filled directly into the cars without the use of buggies to convey the coal to the road side, as is done when the distance between roadways is 30 or 40 yards. Packwalls 6 feet wide are built along each side of the roadways and on but one side in the lifts, as shown in the figure.

When the roadways are close together this system entails a great amount of extra cost in building packwalls and taking down roof, which brings the price paid per ton up to that paid when the pillar and chamber method is used; but, since more lump coal can be produced by the longwall method, the advantage is in its favor, and it is therefore adopted. The cleavage planes are parallel to the dip.

One objection is that under a fairly strong top the packwalls are so close together that sometimes the top does not fall, and when there is not enough refuse to thoroughly stow the open space, or gob, these packwalls become a source of trouble and danger, especially in gassy seams.

1756. Fig. 563 shows a method of longwall as practised at Pemberton Colliery, in Lancashire, England. The seam dips at an inclination of 4° to 5°. Two seams are worked; the one from which the example is taken is 1,698 feet from the surface, and the other is 180 feet below it. The coal from the upper seam is lowered to the lower seam through a pit called a **blind pit,** with two cages, the rope going over a clip pulley. One car is lowered at a time, the full one pulling the empty one up. The coal is brought from the level next the face to the top of the blind pit by means of a self-acting incline.

The roads *r* are driven to the full rise and are 30 yards apart from center to center. They are cut off every 300 feet by levels *c* running about at right angles to them. These levels are 8 feet wide and have packs 12 feet wide built on each side. The roads to the faces or "brows" are 7 feet wide and there are 9-foot packwalls on each side (see Fig. 565). Two feet of top is taken down in the roadway for packing.

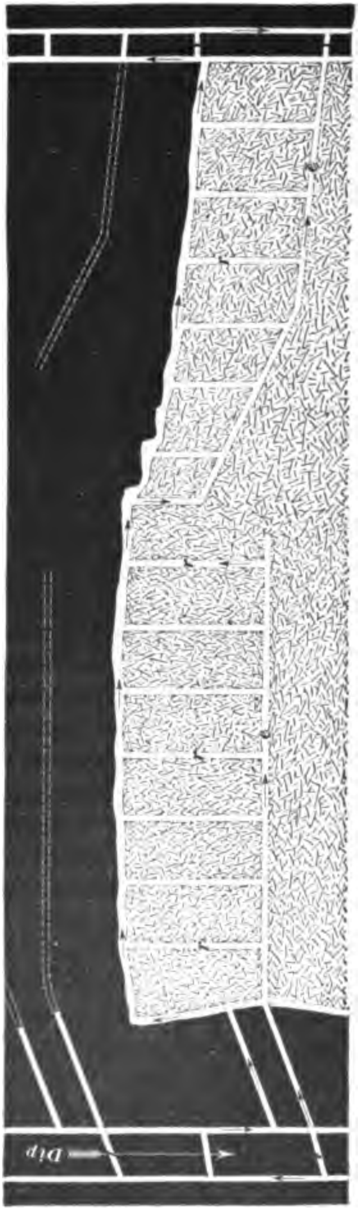


FIG. 563.

There is no regular holing or mining, but when the coal is mined it is done in the 10-inch coal in the center (see Fig. 564). The bottom coal is then lifted up and the top coal supported on props. When these are knocked out the top coal falls. A slight heaving of the bottom greatly assists in taking up the bottom coal. Props and sprags are put in by the miner when required. Four men are in the place on each side of the road, and they deliver their own coal to the self-acting incline.

1757. In addition to the 9-foot packwalls carried on each side of the roads to the face, a double row of chocks *c*, *c* (Figs. 564 and 565), 6 feet apart, is carried all the way along the face. The two rows are laid 5 feet apart, and the car track along the face is laid between them (see Fig. 565). As a third row of chocks is put in, the last one is drawn and shifted forwards. The roof then breaks off behind the chocks. Each chock consists of billets

of wood 2 feet long and 6 inches square, and requires about 5 minutes of one man's time to erect and wedge tight.

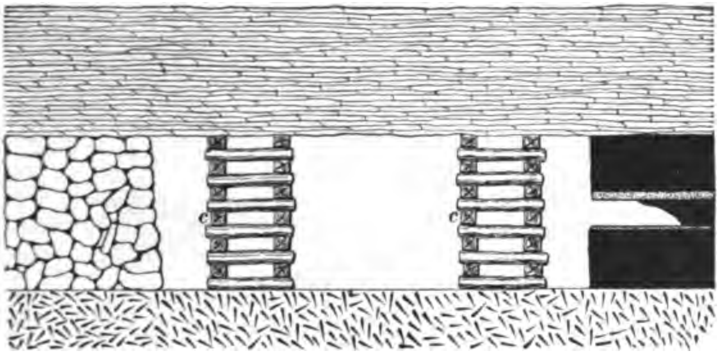


FIG. 564.

They are set on fine dirt or slack for the purpose of being easily removed and distributing the weight equally upon them all.

This system of driving pairs of headings in advance of the

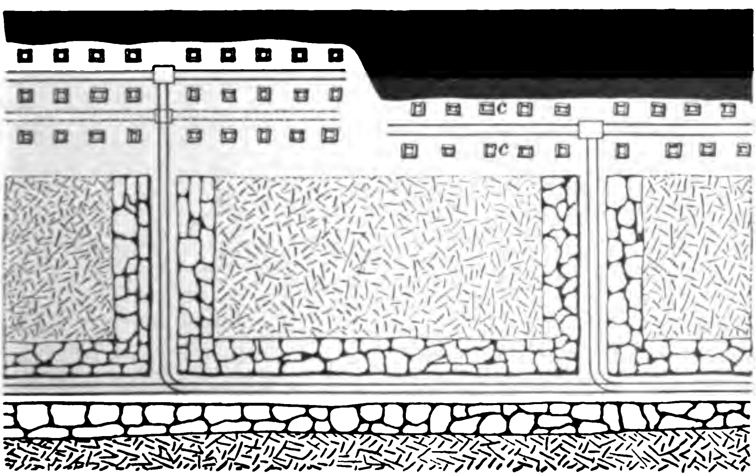


FIG. 565.

range of rooms is used for the purpose of proving the territory ahead of the main workings, or when old workings full

of gas or water under great pressure are being approached. The method also localizes the workings, which, like the panel system, is an advantage in gassy mines; but most of the coal in the pillars protecting the headings, and which is drawn when the boundary of the district is reached, is seriously crushed.

1758. Fig. 566 shows an ideal plan of the longwall method employed at High Part Colliery, Langley Mills, Not-

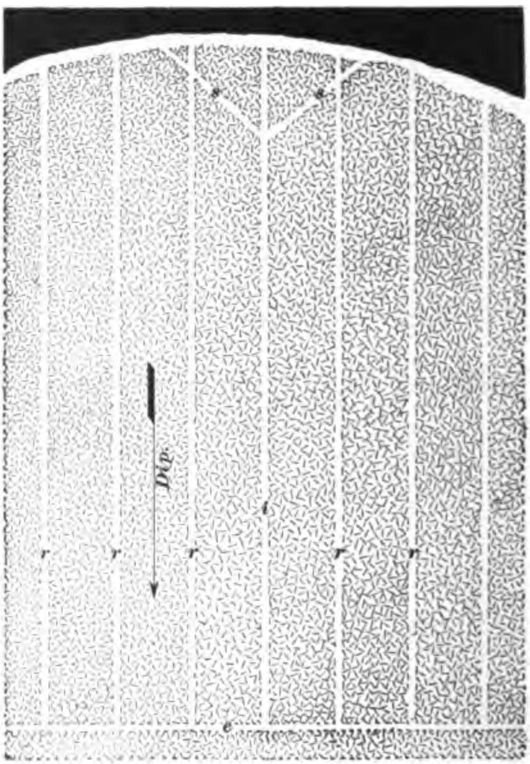


FIG. 566.

tinghamshire, England. The seam is at a depth of 600 feet, and has an inclination of about 3°.

The distance from center to center of the room roads *r* is about 150 feet. These roads run up hill, and are cut off every 1,200 feet by a slope road *s* from the one used as the

main road or self-acting incline plane *i*, down which all the coal is sent to the level *e*. Three feet of the shale roof is taken down in the roads. Below the 2 feet of fireclay in which the holing is done, directly beneath the coal, there is a dark sandstone. The seam is 5 feet 2 inches thick and composed of several layers varying from each other in thickness and quality.

1759. The packs are within 4 feet of the face when the holing or mining is begun, and there is a row of 8-inch props $4\frac{1}{2}$ feet apart along the face. The miners begin at the center and go on holing to both sides, putting in sprags *b* (Fig. 567), 2 feet long, every 6 feet. When necessary, short sprags *a* (Fig. 567), about 15 inches long, are put in

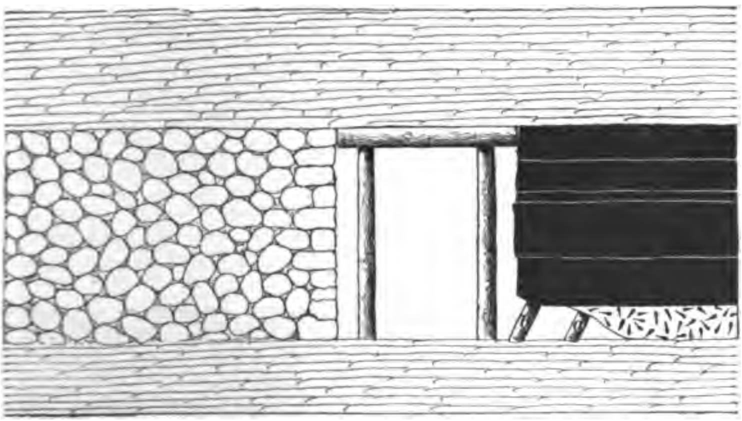


FIG. 567.

underneath the coal, but there is no fixed distance that they should be apart. While the coal is standing on sprags a **shearing** or vertical holing is made at the road-head, 2 feet wide at the beginning and tapering to 3 inches at a depth of about 5 feet. After this is done the miners begin by taking out three or four sprags, and allow the coal they supported to fall.

This is loaded and the roadway laid along the face as shown at *r*, in Fig. 568, which is a plan showing two adjacent

rooms with packwalls and posts. Props and sets of timber are set up over the road (see Fig. 567) about every 4½ feet. One end of the cross-bar is sometimes let into the coal some 3 or 4 inches, and the other end is supported on a prop. When this is done other sprags further on are taken out and the

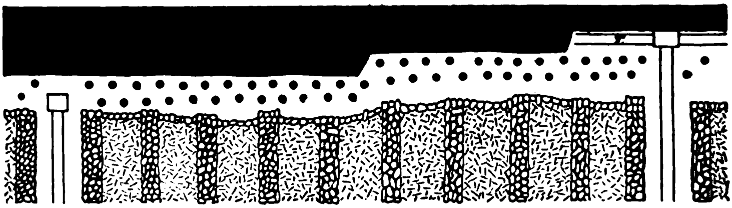


FIG. 568.

coal is loaded. The process is repeated until the end of the room is reached on both sides. When there are two rows of props which are about 5 feet apart behind the sets of timber over the road, the packwalls are built forwards and the props removed. Where the roof is weak or tender, packs about 6 feet wide and 9 feet apart are built of the débris from the road.

1760. Fig. 569 is reduced from the working plan of the Florence Colliery, Longton, in the North Staffordshire

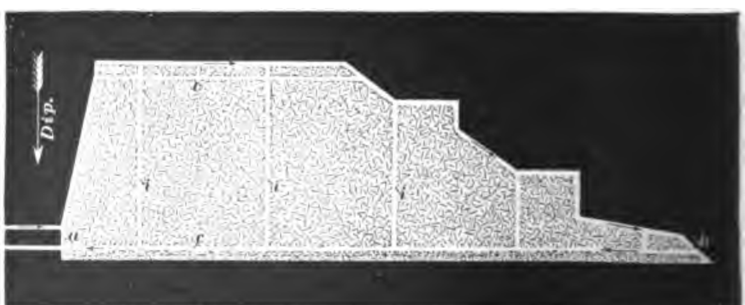


FIG. 569.

(England) district. The depth to the coal is 2,238 feet and it has an inclination of about 8°. Two levels, 10 yards apart, are driven from the shaft bottom for a distance of 1,050 feet, to

point *a* on plan, and at this point a width of 75 feet of coal is taken out. A gob-road *c* is constructed in it, with about 12 feet of packwall on the dip side. The wall, or line of faces, is started from this road, and each face is 254 feet wide, with a road *i* up the center. These roads are cut off by a level *e* every 360 feet. The faces are not all in line, but some are stepped, the one being 45 feet to 60 feet ahead of the other. There is a self-acting incline in each road by which the coal is brought down to the level *c*. It is then drawn along the main level by horses. Chains are used on the inclines.

The roof is 8 feet of fireclay overlaid by a bed of coal

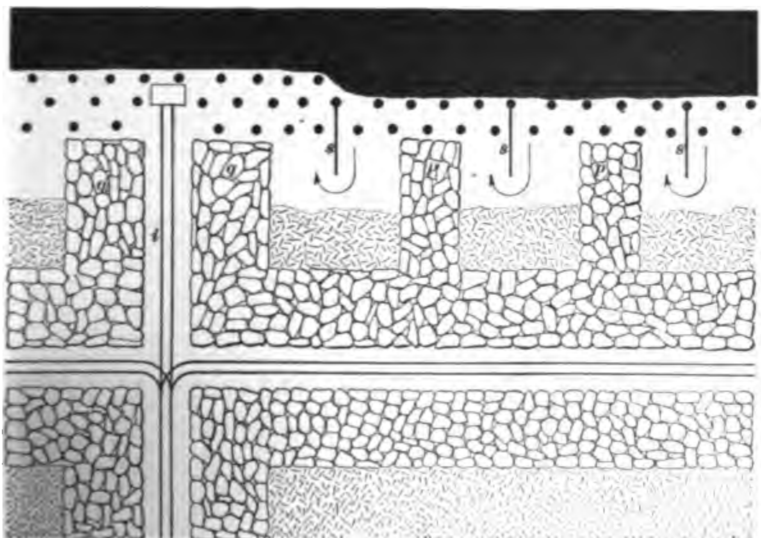


FIG. 570.

2½ feet thick, above which are beds of fireclay and hard, dark shale 8 feet thick, then 8 feet of coal and partings, and then 32 feet of hard, black, slippery clay. The floor is 37 feet of hard shale. The breasting *b* at the face of the level is 75 feet wide, and is kept advanced for opening up fresh roads. Buildings, or packwalls, 9 feet wide, are made along both sides of the roads, which are each 6 feet wide. The arrangement of the props at the face is shown in Fig. 570.

1761. The buildings, or packwalls, are extended every 5 feet, and the rear row of props extracted and advanced. A sprag *a* (Fig. 571) is put under the coal every 6 feet, as the holing is made, and frequently before holing, **cockermegs** are put up along the face. These cockermegs consist of poles *c* (Fig. 571) laid horizontally along the face about 2 feet from the bottom upon short struts *d*, and tightened by other longer struts *b*, one end of each being let slightly into the roof, and the other placed upon the horizontal pole and then driven to place. The space between the packwall on the low side of the level *c* (Fig. 569) and the ribside is kept open as long as possible, and when this can no longer easily be done, a hole is driven through the packwall and a fresh-air course is kept up from this point. There is a chock made of broken timber put up at the corner of each hole. These holes are made about every 120 feet.

The ordinary rooms are 254 feet wide, and 9-foot packs *p*, *p* (Fig. 570) are built parallel to the road 21 feet apart. The packs *q*, *q* next the road are 12 feet wide and are built of stones from 3 feet of brushing, or top, taken down in the

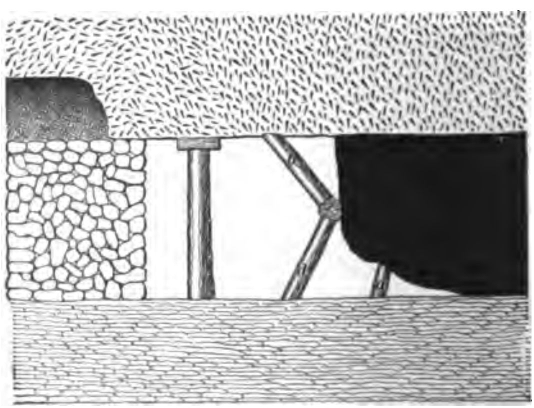


FIG. 571.

road. If this does not furnish sufficient stones for the packs, stones are drawn out of the waste where the top has broken.

After the holing is completed the sprags *a* (Fig. 571), and cockermegs, when used, are drawn and the coal is broken

down by blasting. The props are from 5½ to 6 inches in diameter at the thin end, and there are two rows 4½ feet apart with the props in each row 6 feet apart. If the roof is tender, chocks made of broken timber and built on small coal are put in. There are canvas sheets *s* (Fig. 571) put in from the face for some distance back into the wastes, or gobs, between the packs, and the air is made to travel into the gob.

1762. Fig. 572 shows a system practised in Northern France and Belgium in seams pitching from 10° to 60°, but it is most suitable for pitches ranging from 30° to 60°. The more moderately inclined seams are worked by a road carried up from one level to another, and branch roads are turned off right and left from it about every 20 yards, measured along the inclination of the seam. The coal is taken out for a distance of from 150 to 300 feet on each side of the main incline *i*, and the face presents a series of steps. At intervals slope roads *s* are formed through the gob, cutting off

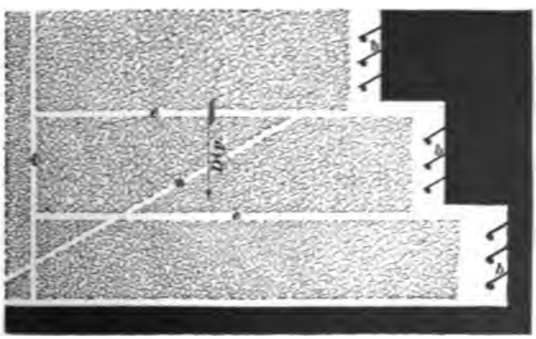


FIG. 572.

the upper levels. When the inclination is 30° to 60°, the track is only laid along the main levels *e*, *e*, which connect with a main self-acting incline *i*. The coal, when loosened by the miner, gravitates down to these levels along the face, and is there loaded into cars. Each face is 60 feet long (measured on the dip), and is worked by four men. For convenience and safety, these men place pieces of board *b*

across the floor horizontally from prop to prop, or face to prop. This also enables the miner to partially regulate the descent of the coal along the face. On moderate pitches slope roads are used, while on steep pitches the incline is used.

1763. Figs. 573 and 575 show the longwall methods of mining two seams simultaneously at Niddrie Colliery, near Edinburgh, Scotland. The coal has an inclination of from 50° to vertical. This colliery was formerly operated by the "stoop and room" method, or a form of it called in Scotland "room and rance," but at a depth beyond 720 feet the difficulties in maintaining roads and getting the coal from the stoops, or rances, increased so rapidly that longwall had to be applied.

The general nature of the workings where the dip does not exceed 70° is shown in Fig. 573, in which *A* is a plan or a horizontal projection of the workings with the strata above the line *u v* on section *C* removed. *B* and *C* are sections through the plan *A* on the lines *m n* and *x y*, respectively. In describing the figure each of the several views will be referred to as marked. Narrow levels *a b*, *c d* (*A* and *B*) are driven in the solid in both the upper or "great" seam and the lower seam from the winding incline *i i* at a depth fixed upon as the bottom of the lift. When a sufficient distance has been reached to ensure the safety of the incline, they are connected by a cross-cut *b d* (*B*) in the rock, and the longwall work is commenced. Section *C* shows that the longwall working in the lower seam is commenced beyond the cross-cuts *b d*, *l o*, and *q p*. A level *b c* (*A* and *B*) is started usually 24 feet wide, having 6 feet of stowage under the rails. The rise side is pillared continuously with wood, the pillars 3 feet thick built checker-board fashion, the open space between being filled with slack.

Chutes *s* (*A*) are branched off, straight to the rise, at intervals of from 24 to 48 feet between centers; they are from 3 to 4 feet wide and are made with concave floors of iron-stone and other hard strata. The gob is stowed with the slack, soft fireclay, and any iron-stone not required for

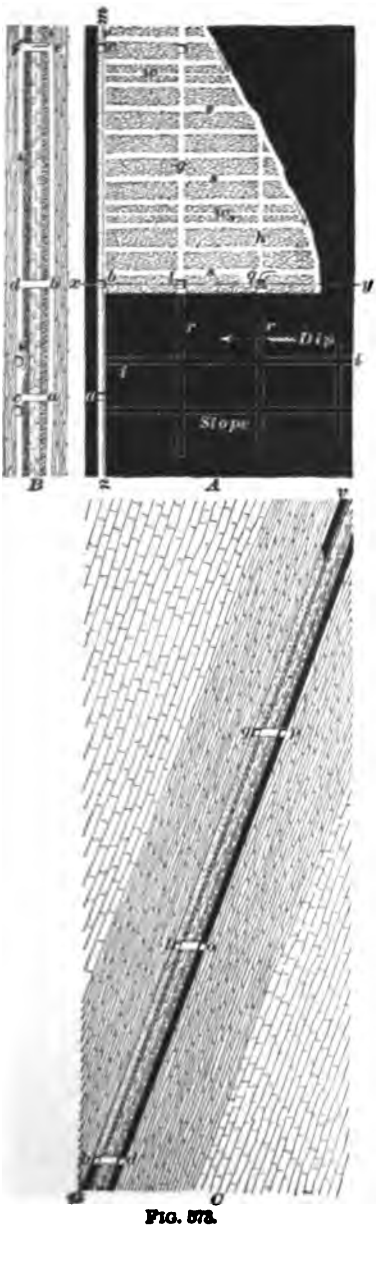


FIG. 578.

packwalls. For the convenience of the miners the walls are arranged so that each has a long rise and a short dip side. The coal is dropped down the chute, at the bottom of which it is loaded into cars.

At intervals of about 210 feet traveling roads *w* (*A*) are formed for the purpose of affording convenient access to the working face at different points. These are built similar to the chutes and are furnished with ladders.

While the longwall working is progressing, roads *r*, *r* (*A*) are driven in the lower seam, at intervals of about 120 feet, and cross-cuts *o l*, *p q* (*C*) are driven therefrom to the great seam, so as to strike this seam before the longwall heading reaches their level. From these cross-cuts intermediate levels *g*, *h* (*A*) are carried across the working faces as they come up, cutting off the chutes. The roads for these immediate levels are laid upon the stowage, and the rise side of the roadway is pillared with wood as in the level below.

The level *d f* (*B*) in the

lower seam is carried in the solid in advance of the long-wall in the great seam. From it cross-cuts *f e* (*B*) are driven connecting the two seams at intervals of 360 to 480 feet for the purpose of cutting off the outside portion of the great seam level as soon as the chutes in it have been cut off by the intermediate level above. The same system is followed with the upper levels, the object being to shorten the life of the roads in the great seam, and to keep the horse or mechanical haulage as close to the working face as possible.

1764. The method of building the levels and chutes is shown in Fig. 574, in which *A* is a plan or horizontal projection taken by supposing all to be removed above the line *m n o p q* shown on section *B*, which is taken along the line *w x y z* on the plan *A*.

The stowage on the dip side of the level tends to prevent the roof breaking and bursting out in the road. Where the seam yields water, drainage is provided for by placing the large blocks of iron-stone and other hard strata at the bottom of the stowage. The top coal is usually taken down in the level, as it is considerably crushed by the roof weight, and when it bursts out it is almost impossible to secure it again. The roof is supported by ordinary half-round bars or slabs *d*, 8 feet long, placed 4 feet apart between centers, and carried by 5-inch props at each end. In some cases a piece of pillar wood or plank is laid longitudinally among the stowage, and the lower end of the crown or cap *d* is driven down between it and the roof, the upper end being carried by a prop *a*. This is found to steady the roof until it has come to rest upon the pillars and stowage.

1765. The pillaring consists of any description of wood that can be obtained cheaply, not less than 3 feet long, and for convenience in building it should be hewed on two sides. The mode of building is as follows: A temporary scaffold is formed of 1-inch bratticing boards about 4 feet long, carried by two props set at a little above a right angle to the plane of stratification, and slightly set into the roof and

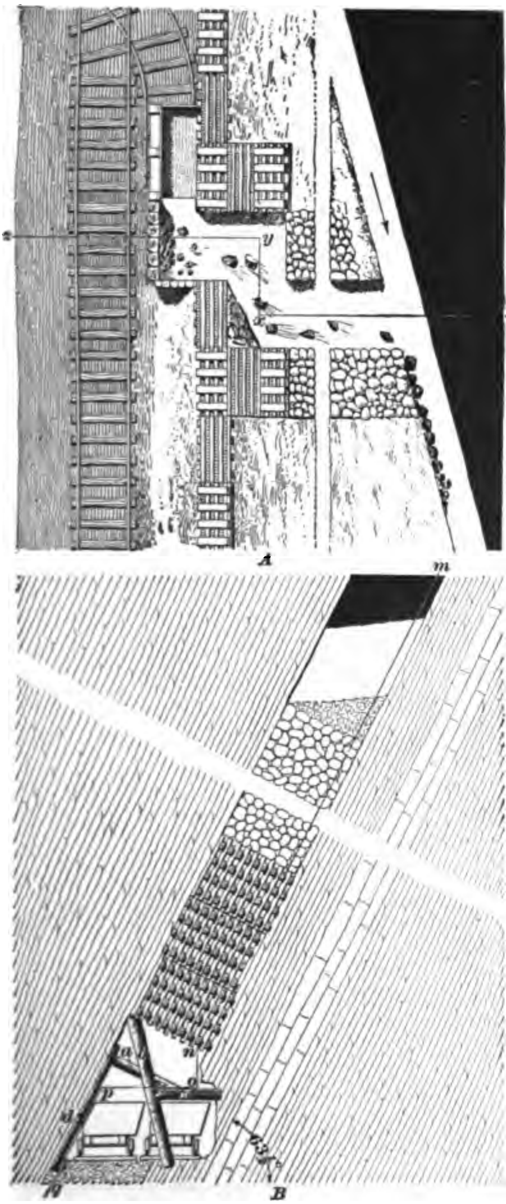


FIG. 571.

floor. Upon this scaffold the pillar is built in alternate courses of header and stretcher, commencing at the pavement, and continuing up to the roof, where the last course is driven in tightly. Each chock, or pillar, is filled in with slack and fine dirt, experience having shown that a pillar of this nature affords a better support to the roof and is less liable to cause it to burst out in the roadways than one built solidly with timber. As soon as the roof weight is seen coming upon the scaffolding props, they are knocked out and the scaffold taken down, the pressure upon the pillars being then amply

sufficient to hold them in position. Many hundreds of these pillars have been put in, and they have never been known to slip.

As soon as the chutes *s* (Fig. 573) in a section of a level, as *b e*, in the lower level, are cut off by the level *g* above, the pillaring is taken out in the corresponding section *b c*, and the wood so drawn is used a second time, and, when used in connection with a little new wood, even a third time.

1766. The distance between levels is determined chiefly by the inclination of the seam and the condition of the pack-walls of the chutes. As the inclination increases, the coal falls down the chute with greater velocity, and the breakage, consequently, become more serious. The iron-stone with which the chutes are built varies considerably in strength, in some places forming very indifferent building material, and when the packwalls begin to give way, the expense of repair is very great. It, therefore, becomes simply a question of arithmetic at what point the reduced value of the output, together with the cost of maintenance of chutes, will warrant the outlay for a new cross-cut and intermediate level.

The shield, or battery, *b c* (Fig. 574) stops the coal at the mouth of the chute, protects the men while passing, and makes a convenient platform off which the coal is loaded into the car. It will be noticed that the battery closes the chute on the outer side. Experience has shown that, when it is so arranged, the air current is much more easily led into the face of the level, and is less dependent upon the screen-doors, which, it is needless to point out, are exceedingly difficult to maintain in perfect condition. The coal is generally worked in lifts of from 360 to 480 feet, and is divided into panels of about 1,200 feet in length.

1767. The plan shown in Fig. 575 is used very successfully on pitches ranging from 70° to 90°. The brake incline and haulage roads are made in the lower seam, as in Fig. 573. Narrow levels *b* in the solid are branched off this incline at

intervals of 56 feet between centers, and from each level a cross-cut *c* is driven to the great seam. The longwall working is commenced on the bottom level, 6 feet of stowage is kept below the rails, and the rise side of the road is pillared continuously, as already described in Art. **1763.** The clear height of the road is $5\frac{1}{2}$ feet. The rise side of the working face is kept trailing, so as to form an angle of 45° with the road. As soon as this level has been opened up

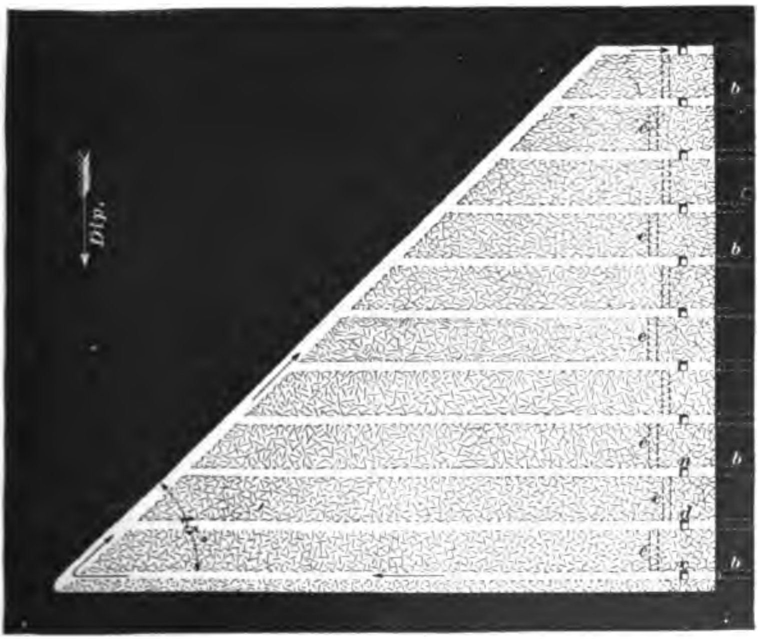


FIG. 575.

sufficiently to let the rise side reach the level of the cross-cut *d*, a road from this cross-cut is laid on the top of the stowage, its rise side being pillared in the same manner as that of the lower level, and the working is extended upwards to the cross-cut *n*, and so on to the top of the brake incline.

The bottom coal generally stands well enough in the roads without timber. The roof, which here forms one side

of the roadway, is supported where necessary with half-round crowns, or caps 8′ × 4″ × 4″, placed 4 feet apart. The upper ends of the crowns are built into the pillaring, and their lower ends are buried in the stowage. As already stated in Art. **1766**, brake inclines are usually about 1,200 feet apart, and from each the coal is worked for a distance of 600 feet on each side. As soon as a road reaches the boundary of the panel, and is thereby cut off, the pillaring is drawn from the coal underneath, and again used, as already described. Communication between the different levels is obtained by means of traveling roads *e* formed in the lower seam and fitted with ladders.

To one not accustomed to edge seam mining, it may appear to be a somewhat dangerous method of working, but experience has shown that this is not the case; and while under the old system of stoop and room it was frequently difficult to get a sufficient number of men for drawing pillars, there is now no difficulty in obtaining men for the longwall workings.

1768. In Nottinghamshire, England, two seams separated by only 7 feet of strata are worked together. The lower seam is 7 feet thick, the seam above is 2 feet thick, and they dip about 3°.

The main levels are driven from the shaft in the lower seam, and the gob-roads are driven at distances of about 180 feet apart, a pillar of about 90 feet being left next the

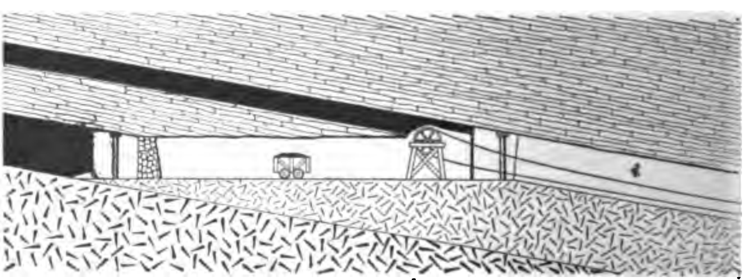


FIG. 576.

level. The lower seam is worked first, and when the workings have advanced about 90 feet, the intervening strata are

taken down, and the débris then acts as a flat at the top of the inclined roads in the upper seam. The position of these seams, and the mode of working them, which is shown in Fig. 576, makes a most convenient flat at a small cost. The cars from the second seam join those from the larger seam at the top of the self-acting incline plane *i*.

1769. Where the seams are highly inclined, very much contorted, and broken up, it is the practice in some districts to sink a vertical shaft *s* (Fig. 577) and drive cross-cuts *c* at

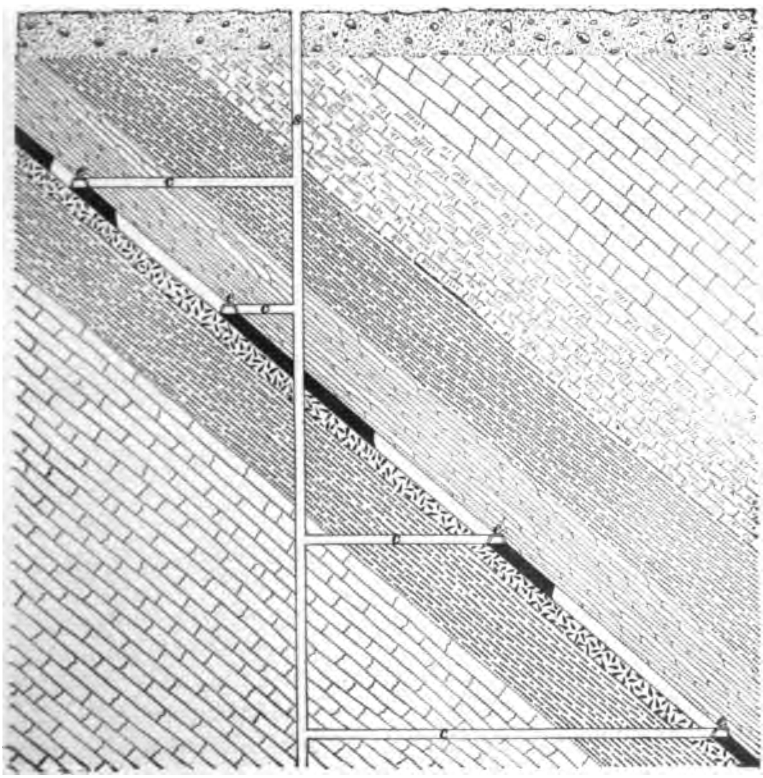


FIG. 577.

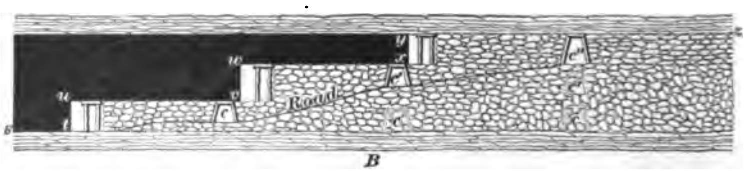
regular distances apart. At the points of intersection of these cross-cuts with the seam, levels *e* are driven right and left. These levels follow the strike of the seam, and as the

inclination is very irregular they are very crooked. The coal is then worked to the rise side of these levels, as shown in the figure.

1770. Fig. 578 shows a method of mining a moderately inclined seam 21 feet thick, in the district of Grande Combe, in the south of France. The plan *A* is taken by supposing the strata to be removed above the line *s t u v w x y z* shown on section *B* which is taken along the line *a b* of the plan *A*, and drawn by increasing the vertical dimensions.

The primary work is in the lower 7 feet of the seam in

A



B

FIG. 578.

which a level *a b* is driven, and from this level inclines *c* from 240 to 300 feet apart are driven to the full rise. Every 30 feet roads *o* are turned off these inclines parallel with the main level. The packs are made of material sent down from the surface into the workings. The car loaded with stone gravitates along the road *c n* to the working places, where it is unloaded and again filled with coal and returned along the heading *a b*.

When the packs consolidate, the floor is heaved up and the

old roads are closed. The roof of the first incline is now cut down and a road c' is formed in the next 7 feet of the coal seam above the old workings, and room roads are started in this layer and carried forward above the old gob. In a similar way the road c'' and a third set of rooms are made in the upper layer, which is also 7 feet thick.

1771. The order of removing the layers may be reversed, or thick seams may have the ordinary methods of longwall applied to them. The seam should be taken out in a number of different lifts formed of layers parallel to the stratification, the top being worked first and the roof allowed to subside on the coal. A 12-foot seam may be divided into two or three lifts, an 18-foot seam into three or four lifts, and so on. It is essential that the gob be well packed. It has been found in either case that in a short time the pack or stowage has been sufficiently consolidated to form a fairly good roof, beneath which the workings may be driven with safety, provided the faces are pushed forward rapidly and plenty of timber is used.

1772. Fig. 579 shows the methods of working a thick seam by longwall at Balgonie, Fifeshire, Scotland, at a depth of 480 feet. The inclination is irregular, varying from flat to 22°. The débris gives off very large quantities of blackdamp ($C\ O_2$). The dark-sectioned portion of the cut shows the first workings in the lower part of the coal, and the light portion shows the second workings in the top of the seam, or where the entire seam is worked out. The workings are opened in sections, consisting of the area between two parallel headings *a b* and *c d*.

A section is commenced by driving the heading *a b* in the bottom coal, or first working, to the rise, and from this heading ordinary working places *p* about 36 feet apart are turned off at nearly right angles to the line of dip. The ordinary working roads are about 10 feet wide; and in order to get height in them the miners take down the coal, which is about 3 feet thick and immediately above the stone parting that makes the natural division between the two workings.

Chocks about 2½ feet square, which consist of the stone just above the first working, and frequently slabs of wood the length of one side of a chock, are put in along the face, the remaining space being fully packed by débris and slack from the coal so that no vacant places will be left. Of course, it is understood that substantial packwalls are built along each side of the roadways.

The holing is made in a thin parting of soft fireclay which is a few inches from the bottom of the coal; but when more débris is required for stowage, the holing is done in

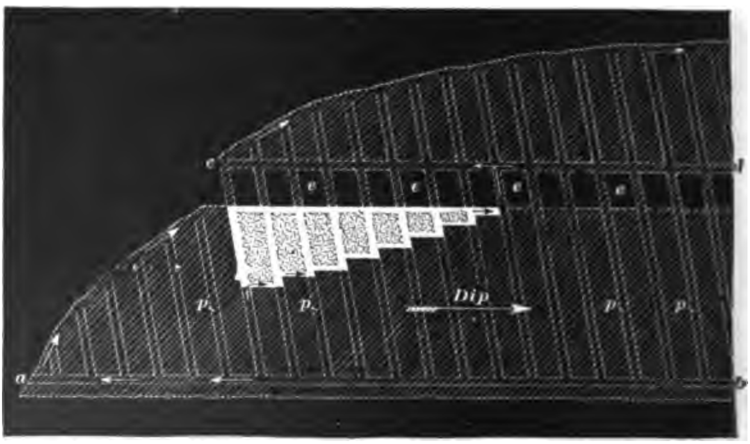


FIG. 579.

the fireclay just below the seam. Where the weight is not too great upon the working face, it is advantageous to make deep minings or undercuts. Props about 5½ feet long are used to a great extent.

While the workings in the heading *a b* are going forwards, another heading *c d* is being driven for the next section, and as the ordinary places turned off the heading *a b* come on to the heading *c d*, they are stopped in the first working, and preparations are made to begin the second workings when convenient. Between the heading *c d* and the working faces of *a b*, a barrier, or stoop, of coal *e e*, etc., about 45 feet thick, is left to protect the heading *c d* in the first working. This

barrier is taken out when the second working of the heading *c d* is in operation.

In the second working the inside places are begun first and lead each other backwards about 15 feet, as the figure shows. Each place is therefore 15 feet in advance of its nearest outside neighbor. To build the packs and stow the waste, a following stone a few inches thick, with the débris and slack, is used, and care is taken to leave no space; but if any spaces must be left for want of material to stow, they are usually left in the old roads. Sometimes, instead of coming back with the second working, they are carried forwards.

Owing to side pressure, the roads are about 6 feet wide, instead of 10 feet, as originally made. By pressure from above and heaving of the floor, the bottom of the coal in the second working and the floor of the first working are almost together. The ventilation in the first working is very simple. To ventilate the second working, the current for the section in the first working is split and part diverted round the faces. At times it is difficult to keep the whole current from traversing the faces of the second working; but when this occurs, means are taken to send all the air to the required section of the first working, and a leakage, which is usually sufficient, is allowed for the second working.

1773. The advantages claimed for this method in thick seams are:

1. That the whole of the available coal is obtained.
2. That the working faces are easily ventilated.
3. That, as to safety, economy, and efficiency, it compares favorably with any other method of working thick seams.
4. That it gives immunity from gob-fires by spontaneous combustion, which the other methods do not.

LONGWALL RETREATING.

1774. Fig. 580 shows a method of opening up a coal field by longwall retreating in which the greater part of the narrow work is deferred until considerable working face is developed. From the vicinity of the shaft bottom, which is near the center of the coal field, four pairs of headings *a* are

driven at right angles to each other to within 500 or 600 feet from the boundary or crop line, where headings *c* are turned off to the right and left. From these headings other pairs of headings *d* are driven directly to the boundary, where they are connected and the working face formed. The headings *c* are driven until they intersect the boundary or crop line,

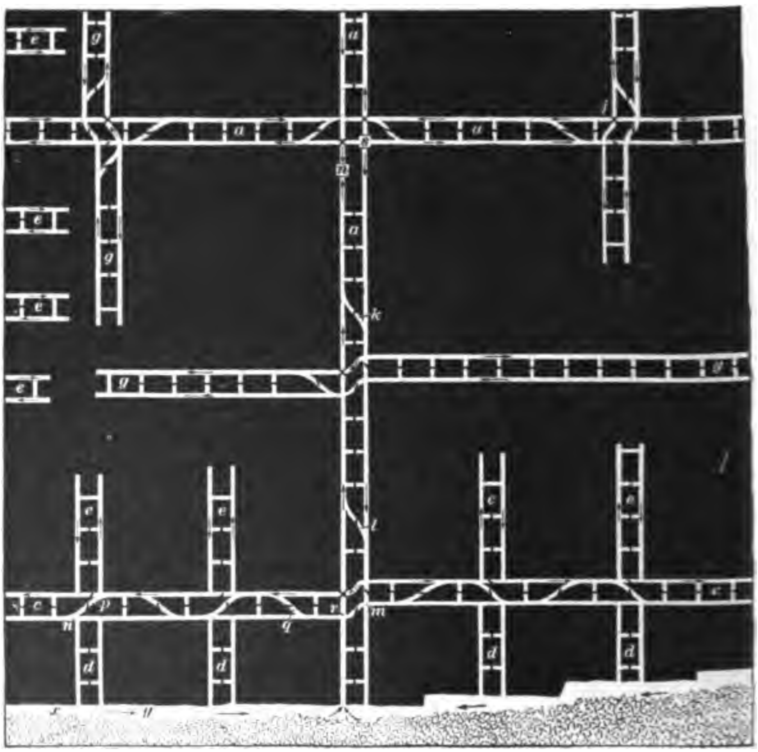


FIG. 580.

or a similar heading coming from one of the other headings *a*. The distance between the headings *d* will depend upon the nature of the coal, top and bottom, and upon the height of the coal.

When the working face is formed and is being drawn back, the headings *e*, which are simply a continuation of the head-

ings *d* in a backward direction, are turned off the headings *c*, and finally cut off by headings *g*. The work is so conducted that when the working face arrives at the headings *c* the headings *e* will have intersected the headings *g* and a condition of affairs similar to that when the working face was first formed will be maintained. This process is continued on all sides until the bottom of the shaft is reached.

1775. This method of longwall retreating not only defers the greater portion of the expense of the narrow work until coal is being produced for the market, but also requires a less amount of track than where parallel headings are driven from the bottom of the shaft directly to the boundary line. As the track is lifted in the headings *d*, it can be laid in the headings *e*, and the only track that may not be reused will be that lifted from the main headings *a* as the working face nears the bottom of the shaft.

The downcast shaft *s* is at the junction of the main headings *a*, where four splits of the air-current are made, and the upcast *n* has such a position with reference to the headings that a landing can be formed on either side of it. The principles governing the working of the face in longwall advancing apply here also.

The method of arranging the diagonal cross-cuts should be carefully noticed, for it is highly important in laying out a mine to know how to arrange the haulage roads so that, in any case, it will not be necessary for one driver to wait on the other. Failing to do this is sure to cause great delay and consequently serious reduction in output Where there are two parallel roads one should be used as the loaded track and the other as the empty track as far as possible.

1776. In order to understand the different arrangements of the diagonal cross-cuts, let us suppose that it is necessary to take a trip of cars from the landing near the foot of the upcast or hoisting shaft *n* to the point *x* at the working face, and return with a loaded trip from the point *y*, while other drivers are going and coming from various parts of the mine.

The driver in charge of the trip would first proceed to the cross-cut *k*, to which point there should be a double track from the foot of the shaft, and then if no driver was coming out of the headings *g* to the right, he would pass through the cross-cut *k* and continue along the straight heading, noticing when he came near the diagonal cross-cut *l* that no driver was coming out of the heading *c* to the right, in which case he would still continue along the straight heading and pass through the cross-cut *m*, where he would again observe that no driver was coming out of the headings *c* to the left, before he would pass through the cross-cut *q*, along the straight heading *c*, through the cross-cut *p*, and finally along the heading *d* to the point *x*. After placing his empty trip, the driver would lead his horse or mule to the point *y*, where he would hitch on the loaded trip and pass out the same heading *d* as he came in until he reached the point *n*, where he would turn and pass along the straight heading directly to the point *r*, where he would again turn and go straight to the landing with his loaded trip. It should be observed that the driver with the empty trip must be on the lookout for drivers coming out with loaded trips, and that the driver coming out has no charge upon him or stops to make.

When, from circumstances before mentioned, it is necessary to drive the pairs of headings *d* close together, only one heading of each pair need have a track in it, because one or more headings are usually assigned to a driver, and there is no danger of one driver running into the other. Under such conditions the arrangement of the cross-cuts, as shown in the headings *c*, is efficient; if, however, the conditions of the mine are such that the pairs of headings *d* can be driven a considerable distance apart, say 100 or 200 yards, then each heading of the different pairs will be provided with a track on which the loads and empties pass over. With this situation of affairs, the cross-cut *p* should connect with the first heading of the extreme left-hand pair *d* rather than with the second of that pair, as shown in the figure, in order to facilitate the haulage from both headings. Similar arrangements should be made at all junctions of the pairs

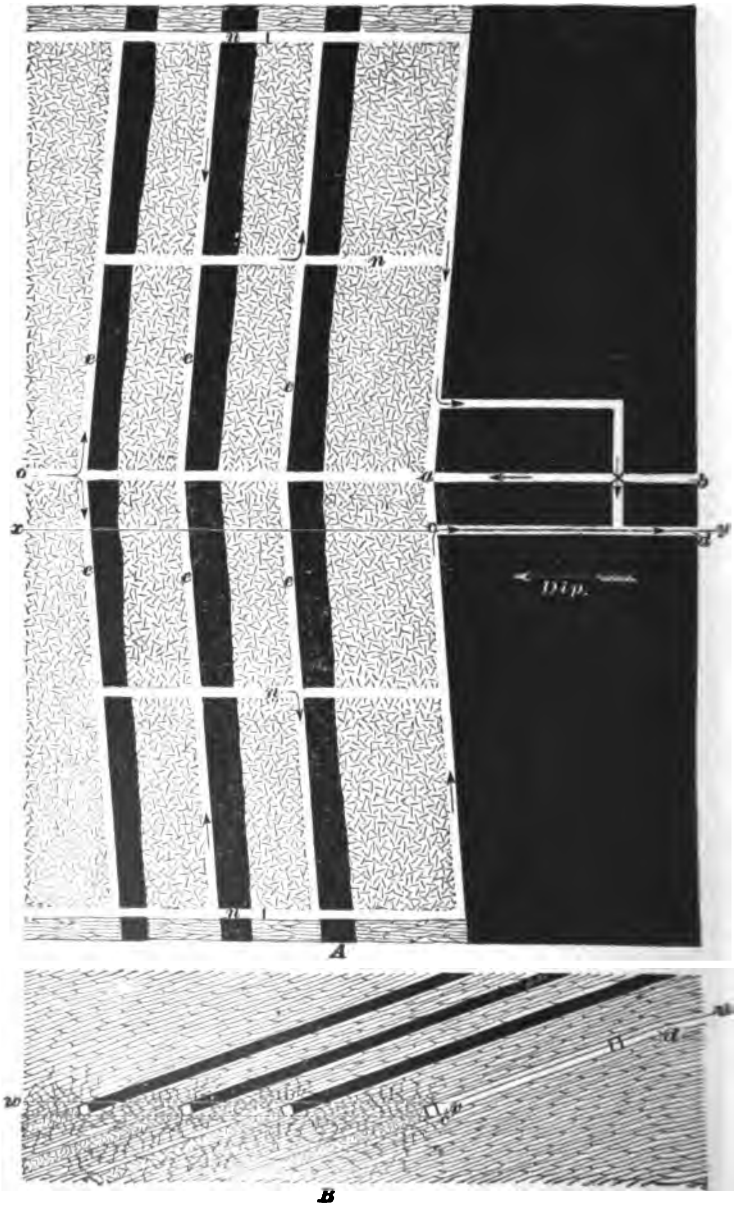
of headings *d* and *c*. One of the pairs of headings branching from the junction *j* will intersect the headings *g*, and, consequently, needs no cross-cut. There is no track laid in the diagonal cross-cuts leading to an overcast nor in the heading beyond until another diagonal cross-cut is met. The above system of laying out the headings requires no backswitching.

1777. At several Warwickshire collieries in England four contiguous seams are worked at a time. Fig. 581 shows a plan *A* taken by supposing the strata above the line *w v u* to be removed, and section *B* taken along the line *x y* of a set of rooms turned off levels in the dip and worked back to the shaft on the forewinning method—longwall retreating. The dotted lines crossing the strata, as shown in section *B*, show the position of the horizontal tunnel *o a*, connecting the working faces of the four seams at the foot of the slope *a b*.

When the rise workings of the pit have been worked out, the main dip incline *a b* of each district is, whenever possible, driven to the boundary of the area to be mined by the shaft. The general way of opening out a district to the dip is as follows:

A pair of roads *a b*, *c d* are driven in the lowest of the seams to be worked, if possible to the boundary, but in all cases a distance of not less than 1,500 or 1,800 feet. A cross-drift *a o* is then driven through all the four seams, and they are each opened out by level headings *e* to a distance of from 450 to 600 feet on each side, and cross-drifts *n* are again driven at each end and generally one in the middle connecting the four seams for ventilation. In this way eight different walls, stalls, rooms, or working places are at once made.

1778. It will be observed that, by working on this system, with such a very thin parting between the seams, there must necessarily be considerable breakage. The faces can not possibly advance at a greater rate than say 1 foot per day, and the distance at which the face of one seam lies



B

FIG. 581.

behind another is only about 30 feet, so that in each case the seam has five or six weeks to settle down. This causes a large percentage of fine coal, and a consequent deterioration in its value before being worked. The ventilation for this method is extremely simple. Descending one incline, the air crosses along the faces, as shown by the arrows, until, finally, the two currents join at the air crossing and proceed up the return. On account of the continuously moving working face, it is necessary to keep the overcast in the slope *a b* some distance ahead in the solid coal.

1779. The main flat *a o* is made to last two or three months, and close to the roadside the faces are allowed to lag slightly behind. It is moved forwards about 60 feet at a time, and while it is being moved forwards the faces close to the roadside are worked up quickly. Every effort is made to let the top settle gently and without breaking by building packs, which are generally about six feet wide and having from 12 to 15 feet of intervening gob between them, so as to save the seam above as much as possible. The material for these packs is obtained from the holing dirt or from that obtained by repairing the main flat. Notwithstanding all precautions, the upper seams are sure to be more or less crushed. Where permanent stoppings or frame doors can not be put in, canvas doors are used.

LONGWALL METHODS COMBINED.

1780. Fig. 582 shows a plan of working a mine by combining longwall advancing and longwall retreating. The upper portion is an ideal plan of Scotch longwall, in which the face is carried forwards in a semicircular form and the roads are turned off each other at angles of 45°, which arrangement, in general, gives best results.

There are numerous roads not more than 8 yards apart leading to the face. Many of these roads, however, are soon cut off by the principal or diagonal roads, and dispensed with; and frequently a number of the diagonal roads are cut off by a cross-cut, which diminishes greatly

the number of permanent haulways to be maintained. It

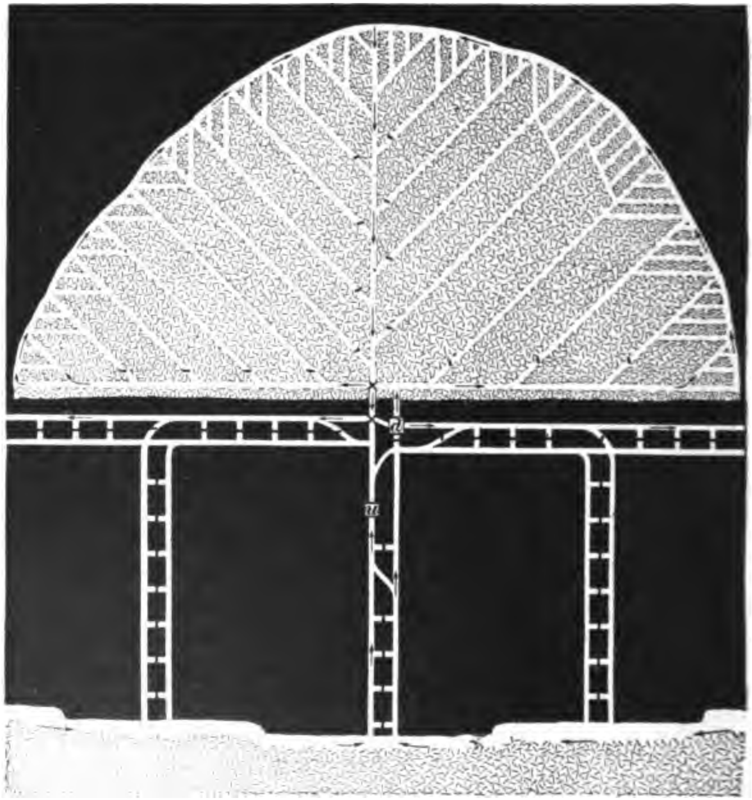


FIG. 582.

is understood that packwalls and chocks are built along the roads, as described through this subject.

1781. This plan of working is suitable for seams up to 3 feet thick, having a weak top, a pitch not greater than 20°, and situated at almost any depth. It is largely the method from which most of the longwall practised in the western United States has been copied.

1782. The lower portion, where the coal is from 4 to 4½ feet thick, is worked on the retreating plan. Narrow head-

ings are driven in pairs to the boundary, and the working face is drawn back towards the shaft. These pair of headings are usually from 200 to 300 feet apart, depending, as stated before, upon the nature of the coal, top and bottom; and the car is taken along the face. A glance at the figure will show the advantages of longwall retreating over longwall advancing; for, in the former, it is obvious that the haulways which are made in the solid coal will not be such a source of trouble as those in the latter, which are made through the gob and maintained by packwalls along each side; also, the course for the air is less broken, even along the working face, for the gob is not cut up by roads formed in it, as is the case in longwall advancing. This system is indisputably the best for good and efficient ventilation and haulage, particularly mechanical haulage; and perhaps the only objection to it is that it will not yield returns as soon as the advancing system; though, in the end, it is the most satisfactory and profitable.

1783. Such a combination of systems enables the operator to get an unvarying supply of coal, for, while the working force on one side is continually leaving the shaft, the one on the other side is approaching it. The location of the downcast with reference to the workings is a matter of choice, but in virgin coal fields the upcast *u* and the downcast *d* must necessarily be within a reasonable distance of each other, in order to secure, as early as possible, a permanent return airway. The coal in this plan is mostly caged on that side of the shaft next the longwall advancing, and one of each pair of headings is used for the loaded, and the other for the empty cars, as the arrangement of the diagonal cross-cuts will suggest after having studied Fig. 580.

1784. It should be borne in mind that the principal points to be considered in longwall working are :

1. The direction in which the working face should advance with reference to the cleavage planes of the coal, and to the dip of the strata; for upon the determination of the

proper direction will depend the best manner of supporting the roof and of getting the greatest amount of lump coal.

2. Whether the working face should be kept in a continuous line or stepped; for this also affects the maintenance of the roof and the size of the coal obtained.

3. The rate of advance of the working face. Sometimes it is advantageous to allow the web of coal to remain unsupported upon the sprags or cockers until the pressure of the roof acts upon it; while, on the other hand, it is sometimes best to advance the working face as fast as possible.

4. The proper building of the packwalls and the stowage of the gob. The packwalls should be built as strong as possible, carried close up to the roof, and kept well up to the face; where there is sufficient available material it is always best to stow the gob completely.

1785. In conclusion it is scarcely necessary to say that the system is applied to seams varying much in thickness, depth, and in the nature of their roof and floor. With a straight or uniformly curved face and the bearing in properly done, it is undoubtedly the best system to obtain the greatest percentage of lump coal and to get the largest proportion of the entire seam at a minimum cost; but where roadways must be made close together and the roof and floor are hard, requiring the use of explosives, it is doubtful if the system has any advantage over the pillar and chamber method.

The use of longwall methods in the United States is becoming more general; and the fact that it is now being recognized that our supply of coal is limited, *exhaustive mining* is becoming of *great* importance in determining mining methods.

1786. It is claimed that longwall, particularly longwall retreating, could be applied to many of the low and moderately inclined anthracite seams with almost inestimable advantages over the present system; indeed, theory strongly upholds that such would be the case, and a great deal of experience on the Eastern Continent corroborates the theory.

The principal difficulty of introducing longwall in the anthracite region for some seams seem to be that no operator desires to take the risk of giving the system a fair trial in the hands of experienced men, so long as he can profitably operate upon the established plan.

1787. Longwall advancing has been tried on a small scale in some parts of the anthracite region without success. Longwall retreating, which seems to be the most likely method of working many anthracite seams on a more economic and exhaustive plan than is now in use, has not yet been tried. It not only requires a radical change in the mine cars, but also requires that the operator wait until nearly all narrow work is driven before he can get any returns, something very much in opposition to the principles (perhaps conditions) of the American operator.

CREEP IN LONGWALL.

1788. Creep in longwall is simply a swelling up of the bottom in the roads, caused by the weight resting heavily on the roadside packs. Where there is a soft fireclay (hard fireclay may be made soft by moisture) floor, and the gob is not very fully stowed, the packs will receive a great amount of pressure, and the soft fireclay naturally swells up in the spaces on each side of the packs, and as the heaving up meets with practically no resistance in the roadways, they may become closed up entirely. There are few cases of longwall where creep does not take place to some extent, although, where the gob is stowed completely, the weight of the overlying strata is distributed almost entirely over the bottom, and the conditions for creep—the concentration of the superincumbent pressure upon a small area of the bottom—are entirely avoided.

1789. Fig. 583 shows a longitudinal section *A* and a cross-section *B* through a road in longwall workings in which a creep has occurred. The cross-section *B* is taken through the line *a b*, and the longitudinal section through the line *f e*. It will be observed that the packwalls *p* on

either side of the road *r* are forced into the bottom by the enormous weight of the roof, and a consequent upheaval

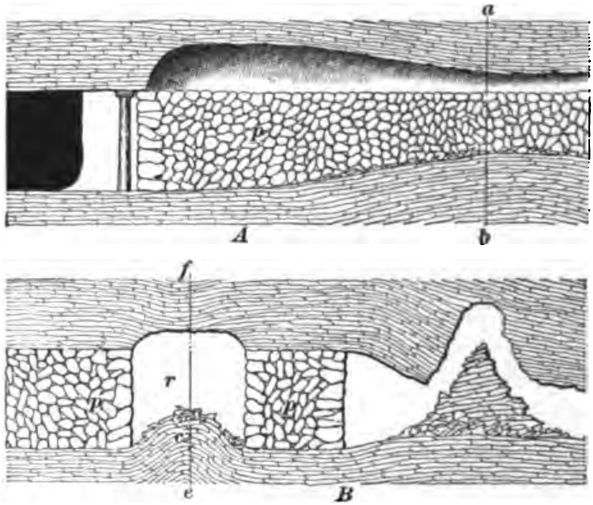


FIG. 588.

of the bottom, or creep *c*, on both sides of the packs is produced.

The degree of creep is greater in the road than on the far sides of the packwalls, because it is due to the combined effect of both packwalls. The shaded portion of the roof in the longitudinal section *A* shows the amount of roof that has been taken down in the road to secure height, also the way in which the creep has affected the roof.

1790. It is a very difficult matter, if not impossible, to stop a creep when it gets a start. Therefore, it is imperative to guard against accident by building the packwalls, in the first place, sufficiently wide and strong to be on the safe side.

TESTING THE ROOF.

1791. It is one of the important duties of a mine official to see that the roof in hauling roads, traveling roads, and even in working places is in a safe condition.

The safety of the roof is judged by general appearances and the sound produced on tapping it with a small hammer

or other tool. If it looks solid and the sound indicates that it is so, the roof is usually safe; but this alone should not be implicitly relied on. The lamp should be held up to the roof, and a careful scrutiny be made for joints, or cracks.

The sound may sometimes indicate that a stone is solid when it is not. This deceptive indication is generally due to the large size of the stone. Bell-shaped, wedge-shaped, and other loose pieces in an otherwise solid rock roof also emit a solid sound when struck with a pick or hammer. If a hollow sound is emitted when the roof is struck, the stone is unsafe and should be taken down, or timber set up under it. The sides must also be examined; this is usually done by carefully examining them with the aid of the lamp.

DRAWING TIMBER.

1792. The principal object in drawing the *back timbers* and breaking up small coal pillars (if any be left in) is to enable the roof to settle regularly and to release the weight at the face. This weight would otherwise become excessive and reduce the percentage of lump coal. It would also increase the amount of slack, and would cause the weight to crawl over the pillars and destroy them.

Accidents have occurred from the back timbers having been left in too long. Although timber-drawing is dangerous, if the timber is left in, the danger increases considerably irrespective of the waste of timber which it entails.

1793. The timbers should be removed as quickly as possible after the work is started, always allowing a sufficient number of props at the face where miners are working.

The removed props can generally be used several times. Even when the removed timber is broken, it can be used for cap pieces or in building chocks or nogs.

Great judgment and experience are required to ensure that the best order of drawing props will be adopted, especially where there is a considerable area of waste. It may be best to leave a few props behind to assist in recovering the others with a little more safety. Where the top is too

dangerous, the props must not be drawn if there is danger to the workmen in so doing. Removing one prop sometimes starts the roof, which falls, bringing a number of posts with it. The props in the rear row should be drawn first. Not more than one prop should be drawn at a time, and there should be perfect silence while this is being done. There should never be less than two or three men present who take part in this work.

1794. Timber is drawn in several ways. The tools and appliances used for this purpose are shown in Fig. 584. The

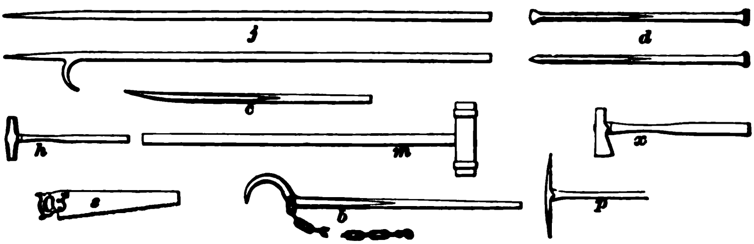


FIG. 584.

first thing to be done in drawing a prop is to loosen it at the top or bottom, depending upon which point is the most accessible and the ease and convenience with which the work can be accomplished, by means of a pick *p*, crowbar *c*, or drill

FIG. 585.

d. With a pretty safe roof, the prop is knocked out with a hammer *h* after all loose pieces have been carefully removed.

Where the top can not be depended upon, the workman jumps back immediately after the blow is delivered on the head of the prop. The blows are repeated until the prop falls, but between each blow the workman waits and listens for a sign of the roof giving way. When the prop falls, one of the workmen promptly sticks his pick *p* or jobber *j* into it and drags it out, in this way avoiding that portion of the roof from which the support has just been removed. In many cases the prop, after having been loosened with a pick, is loosened still further by hammering, after which a dog and chain *b* is applied from another prop, at a safe distance, and the prop levered out with safety (see Fig. 585).

1795. When the foot of the prop is inaccessible or the post is heavily weighted, it is cut with a sharp ax. This is a dangerous practice, especially in thick seams, and quite unnecessary, because the work of "throwing" the props can be done safely and in a thorough manner by boring a shallow hole in the prop with an auger and inserting therein 1 inch of a stick of dynamite, by which the prop is broken up.

In cases where only the head of the prop is accessible, a dog and chain is applied to it in such a way as to draw it up. The chain is thrown around the prop, and forms a noose into which the end of the dog is inserted. The dog rests on a post placed horizontally near the one which it is intended to draw. The grip of the chain tightens as the force is applied to lift the prop.

1796. An additional help in use at some collieries is

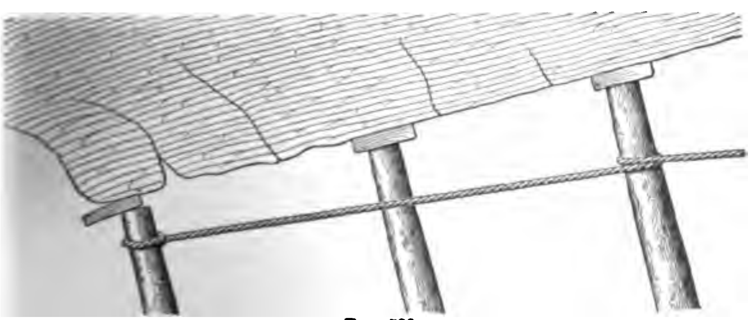


FIG. 586.

shown in Fig. 586. It consists of a rope 7 yards long, with

a hook to it. The end with the hook is lashed round the prop which is to be drawn, and the other end is securely fastened to a firmly set prop at some distance to the rise. After the prop has been sufficiently loosened, or while it is being hammered, or while the dog and chain are being applied, a sudden jerk produced by one or two men throwing their weight upon the tightened rope near its middle point will greatly help to loosen the prop and enable the men to drag it out immediately and with safety.

1797. Timber drawing in connection with falling and cutting down top coal requires more care than ordinary timber drawing, inasmuch as the object is not only to draw the props, but also to get out as much coal as possible.

1798. When the back timber is drawn and the roof allowed to settle in the waste, or gob, it acts as a lever, the fulcrum of which lies over the end of the mining or holing, and exerts a slight pressure on the face of the coal. But in many cases, if the back timber is not drawn, excessive weight is thrown forward on the faces, and, instead of assisting in the next mining, the result is that the coal is made tougher, and, consequently, the operation of holing or mining more difficult to perform. In many cases, however, this excessive pressure causes the roof to break off at the face, destroying entirely the beneficial effects of the leverage for the next mining.

MECHANICS.

(PART 1.)

MATTER AND ITS PROPERTIES.

1799. Matter is anything that occupies space. It is the substance of which all bodies are composed. Matter is composed of *molecules* and *atoms.*

1800. A **molecule** is the smallest portion of matter than can exist without changing its nature.

1801. An **atom** is an indivisible portion of matter.

Atoms unite to form molecules, and a collection of molecules form a mass or body.

A drop of water may be divided and subdivided, until each particle is so small that it can only be seen by the most powerful microscope, but each particle will still be water. Now, imagine the division to be carried on still further, until a limit is reached beyond which it is impossible to go without changing the nature of the particle. The particle of water is now so small that, if it be divided again, it will cease to be water, and will be something else; we call this particle a *molecule.*

If a molecule of water be divided, it will yield two atoms of hydrogen gas, and one of oxygen gas. If a molecule of sulphuric acid be divided, it will yield two atoms of hydrogen, one of sulphur, and four of oxygen.

It has been calculated that the diameter of a molecule is larger than $\frac{1}{1250000000}$ of an inch, and smaller than $\frac{1}{500000000}$ of an inch.

1802. Bodies are composed of collections of molecules. Matter exists in three conditions or forms: *solid*, *liquid*, and *gaseous.*

1803. A **solid body** is one whose molecules change their relative positions with great difficulty; as iron, wood, stone, etc.

1804. A **liquid body** is one whose molecules tend to change their relative positions easily. Liquids readily adapt themselves to the vessel which contains them, and their upper surface always tends to become perfectly level. Water, mercury, molasses, etc., are liquids.

1805. A **gaseous body,** or gas, is one whose molecules tend to separate from one another; as air, oxygen, hydrogen, etc.

Gaseous bodies are sometimes called **aeriform** (air-like) **bodies.** They are divided into two classes—the so-called "*permanent*" *gases* and *vapors.*

A **permanent gas** is one which remains a gas at ordinary temperatures and pressures.

A **vapor** is a body which, at ordinary temperatures, is a liquid or solid, but, when heat is applied, becomes a gas, as steam.

1806. One body may be in all three states; as, for example, mercury, which at ordinary temperatures is a liquid, becomes a solid (freezes) at 40° below zero, and a vapor (gas) at 600° above zero. By means of great cold, all gases, even hydrogen, have been liquefied, and some solidified.

By means of heat, all solids have been liquefied, and a great many vaporized. It is probable that, if we had the means of producing sufficiently great extremes of heat and cold, all solids might be converted into gases, and all gases into solids.

1807. Every portion of matter possesses certain qualities called *properties.* Properties of matter are divided into two classes, *general* and *special.*

General properties of matter are those which are common to all bodies. They are as follows: ***Extension***, *impenetrability*, *weight*, *indestructibility*, *inertia*, ***mobility***,

divisibility, *porosity*, *compressibility*, *expansibility*, and *elasticity*.

1808. Extension is the property of occupying space. Since all bodies must occupy space, it follows that extension is a general property.

By **impenetrability** we mean that no two bodies can occupy exactly the same space at the same time.

1809. Weight is the measure of the earth's attraction upon a body. All bodies have weight. In former times it was supposed that gases had no weight, since, if unconfined, they tend to move away from the earth, but, nevertheless, they will finally reach a point beyond which they can not go, being held in suspension by the earth's attraction. Weight is measured by comparison with a standard. The standard is a bar of platinum owned and kept by the Government; it weighs one pound.

1810. Inertia means that a body can not put itself in motion nor bring itself to rest. To do either, it must be acted upon by some force.

1811. Mobility means that a body can be changed in position by some force acting upon it.

1812. Divisibility is that property of matter which indicates that a body may be separated into parts.

1813. Porosity is that property of matter which indicates that there is space between the molecules of a body. Molecules of a body are supposed to be spherical, and, hence, there is space between them, as there would be between peaches in a basket. The molecules of water are larger than those of salt; so that when salt is dissolved in water, its molecules wedge themselves between the molecules of the water, and unless too much salt is added, the water will occupy no more space than it did before. This does not prove that water is penetrable, for the molecules of salt occupy the space that the molecules of water did not.

Water has been forced through iron by pressure, thus proving that iron is porous.

1814. Compressibility is that property of matter which indicates that the molecules of a body may be crowded nearer together, so as to occupy a smaller space.

1815. Expansibility is that property of matter which indicates that the molecules of a body may be forced apart, so as to occupy a greater space.

1816. Elasticity is that property of matter which indicates that if a body be distorted within certain limits, it will resume its original form when the distorting force is removed. Glass, ivory, and steel are very elastic.

1817. Indestructibility indicates that matter can never be destroyed. A body may undergo thousands of changes; be resolved into its molecules, and its molecules into atoms, which may unite with other atoms to form other molecules and bodies entirely different from the original body, but the same number of atoms remain. The whole number of atoms in the universe is exactly the same now as it was millions of years ago, and will always be the same. *Matter is indestructible.*

1818. Special properties are those which are not possessed by all bodies. Some of the most important are as follows: *Hardness*, *tenacity*, *brittleness*, *malleability*, and *ductility*.

1819. Hardness is that property of matter which indicates that some bodies may scratch other bodies. Fluids and gases do not possess hardness. The diamond is the hardest of all substances.

1820. Tenacity is that property of matter which indicates that some bodies resist a force tending to pull them apart. Steel is very tenacious.

1821. Brittleness is that property of matter which indicates that some bodies are easily broken; as glass, crockery, etc.

1822. Malleability is that property of matter which indicates that some bodies may be hammered or rolled into sheets. Gold is the most malleable of all substances.

1823. Ductility is that property of matter which indicates that some bodies may be drawn into wire. Platinum is the most ductile of substances.

MOTION AND VELOCITY.

1824. Motion is the opposite of rest, and indicates a changing of position in relation to some object. If a large stone is rolled down hill, it is in motion in relation to the hill.

If a person is on a railway-train, and walks in the opposite direction from that in which the train is moving, and with the same speed, he will be in motion as regards the train, but at rest with respect to the earth, since, until he gets to the end of the train, he will be directly over the spot at which he was when he started to walk.

1825. The **path** of a body in motion is the line described by its *central point*. No matter how irregular the shape of the body may be, nor how many turns and twists it may make, the line which indicates the direction of the center of the body for every instant that it was in motion is the path of the body.

1826. Velocity is rate of motion. It is measured by a unit of space passed over in a unit of time. When equal spaces are passed over in equal times, the velocity is said to be **uniform.** In all other cases, it is **variable.**

If the fly-wheel of an engine keeps up a constant speed of a certain number of revolutions per minute, the velocity of any point is uniform. A railway-train having a constant speed of 40 miles per hour moves 40 miles every hour, or $\frac{40}{60} = \frac{2}{3}$ of a mile every minute, and since equal spaces are passed over in equal times, the velocity is uniform.

1827. To find the uniform velocity which a body must have to pass over a certain distance or space in a given time :

Rule.—*Divide the distance by the time.*

Let s = distance traveled by moving body;
v = uniform velocity of body;
t = the time.

Then, $$v = \frac{s}{t}. \qquad \textbf{(90.)}$$

EXAMPLE.—The piston of a steam-engine travels 3,000 feet in 5 minutes; what is its velocity in feet per minute?

SOLUTION.—Here 3,000 feet is the distance, and 5 minutes is the time. Applying formula **90**,

$$v = \frac{s}{t} = \frac{3,000}{5} = 600 \text{ feet per minute. Ans.}$$

CAUTION.—Before applying the above or any of the succeeding rules, care must be taken to reduce the values given to the denominations required in the answer. Thus, had the velocity been required to have been in feet per second instead of feet per minute in the above example, the 5 minutes should first be reduced to seconds before dividing. The operation would then have been 5 min. $= 5 \times 60 = 300$ sec. Then, according to the formula,

$$v = 3,000 \div 300 = 10 \text{ ft. per sec. Ans.}$$

Had the velocity been required in inches per second, it would have been necessary to reduce the 3,000 feet to inches and the 5 minutes to seconds before dividing. Thus, 3,000 ft. $\times 12 = 36,000$ in. 5 min. $\times 60 = 300$ sec. Now, applying the formula,

$$v = \frac{36,000}{300} = 120 \text{ in. per sec. Ans.}$$

EXAMPLE.—A railroad-train travels 50 miles in $1\frac{1}{2}$ hours; what is its average velocity in feet per second?

SOLUTION.—Reducing the miles to feet and the hours to seconds, 50 miles $\times 5,280 = 264,000$ ft. $1\frac{1}{2}$ hours $\times 60 \times 60 = 5,400$ sec. Applying formula **90**,

$$v = \frac{264,000}{5,400} = 48\tfrac{8}{9} \text{ ft. per sec. Ans.}$$

1828. To find the distance which a body would travel in a given time with a given velocity:

Rule.—*Multiply the velocity by the time,*

or $$s = v\,t. \qquad \textbf{(91.)}$$

EXAMPLE.—The velocity of sound in still air is 1,092 feet per second: how many miles will it travel in 16 seconds?

SOLUTION.—Reducing the 1,092 ft. to miles, the velocity is

$$\frac{1{,}092}{5{,}280} \text{ mile per second.}$$

Applying formula **91**,

$$s = v\,t = \frac{1{,}092}{5{,}280} \times 16 = 3.31 \text{ miles, nearly. Ans.}$$

EXAMPLE.—The piston speed of an engine is 11 ft. per sec.; how many miles does the piston travel in 1 hour and 15 minutes?

SOLUTION.— 1 hour and 15 minutes reduced to seconds = 4,500 seconds = the time. 11 feet reduced to miles $= \frac{11}{5{,}280}$ mile = velocity in miles per second. Applying the formula,

$$s = \frac{11}{5{,}280} \times 4{,}500 = 9.375 \text{ miles. Ans.}$$

1829. To find the time it will take a body to move through a given distance with a given uniform velocity:

Rule.—*Divide the distance, or space passed over, by the velocity.*

$$t = \frac{s}{v}. \qquad \textbf{(92.)}$$

EXAMPLE.—Suppose that the radius of the crank of a steam-engine is 15 inches and that the shaft makes 120 revolutions per minute, how long will it take the crank-pin to travel 18,849.6 feet?

SOLUTION.—Since the radius, or distance from the center of the shaft to the center of the crank-pin, is 15 in., the diameter of the circle it moves in is 15 in. × 2 = 30 in. = 2.5 ft. The circumference of this circle is 2.5 × 3.1416 = 7.854 ft. 7.854 × 120 = 942.48 ft. = distance that the crank-pin travels in one minute = velocity in feet per minute. Applying the formula,

$$t = \frac{s}{v} = \frac{18{,}849.6}{942.48} = 20 \text{ min. Ans.}$$

EXAMPLE.—A point on the rim of an engine fly-wheel travels at the rate of 150 feet per second: how long will it take to travel 45,000 feet?

SOLUTION.—Using formula **92**,

$$t = \frac{45{,}000}{150} = 300 \text{ sec.} = 5 \text{ min. Ans.}$$

EXAMPLES FOR PRACTICE.

1. A locomotive has drivers 80 inches in diameter. If they make 293 revolutions per minute, what is the velocity of the train in (*a*) feet per second? (*b*) miles per hour?

Ans. $\begin{cases} (a) \text{ 102.277 ft. per sec.} \\ (b) \text{ 69.734 mi. per hr.} \end{cases}$

2. Assuming the velocity of steam as it enters the cylinder to be 900 feet per second, how far could it travel, if unobstructed, during the time the fly-wheel of an engine revolved 7 times, if the number of revolutions per minute were 120? Ans. 3,150 ft.

3. The average speed of the piston of an engine is 528 feet per minute; how long will it take the piston to travel 4 miles?

Ans. 40 min.

4. A speed of 40 miles per hour equals how many feet per second?

Ans. $58\frac{2}{3}$ ft.

5. The earth turns around once in 24 hours. If the diameter be taken as 8,000 miles, what is the velocity of a point on the earth in miles per minute? Ans. $17.45\frac{1}{3}$ mi. per min.

6. The stroke of an engine is 28 inches. If the engine makes 11,400 strokes per hour, (*a*) what is its speed in feet per minute? (*b*) How far will this piston travel in 11 minutes?

Ans. $\begin{cases} (a) \text{ } 443\frac{1}{3} \text{ ft. per min.} \\ (b) \text{ 4,876 ft. 8 in.} \end{cases}$

FORCE.

NEWTON'S LAWS OF MOTION.

1830. A **force** is that which produces, or tends to produce or destroy, motion. Forces are called by various names, according to the effects which they produce upon a body, as *attraction*, *repulsion*, *cohesion*, *adhesion*, *accelerating* force, *retarding* force, *resisting* force, etc., but all are equivalent to a push or pull, according to the direction in which they act upon a body.

1831. That the effect of a force upon a body may be compared with another force, it is necessary that three conditions be fulfilled in regard to both bodies. They are as follows:

1. *The point of application, or point at which the force acts upon the body, must be known.*

2. *The direction of the force, or, what is the same thing, the straight line along which the force tends to move the point of application, must be known.*

3. *The magnitude or value of the force, when compared with a given standard, must be known.*

The unit of magnitude of forces will always be taken as one pound, and all forces will be spoken of as a certain number of pounds.

1832. In practice, force is always regarded as a pressure; that is, a force may always be replaced by an equivalent weight. Thus, a force of 20 lb. acting upon a body is regarded as a pressure of 20 lb. produced by a weight of 20 lb. The tendency of a force is always to produce motion in the direction in which it acts. The resistance may be too great to cause motion, but it *always tends* to produce it.

1833. The fundamental principles of the relations between force and motion were first stated by Sir Isaac Newton. They are called "Newton's Three Laws of Motion," and are as follows:

I. *All bodies continue in a state of rest, or of uniform motion in a straight line, unless acted upon by some external force that compels a change.*

II. *Every motion or change of motion is proportional to the acting force, and takes place in the direction of the straight line along which the force acts.*

III. *To every action there is always opposed an equal and contrary reaction.*

1834. In the *first law of motion* it is stated that a body once set in motion by any force, no matter how small, will move forever in a straight line, and always with the same velocity, unless acted upon by some other force which compels a change. It is not possible to actually verify this law, on account of the earth's attraction for all bodies, but from astronomical observations, we are certain that the law is true. This law is often called *the law of inertia.*

1835. The word **inertia** is so abused that a full understanding of its meaning is necessary. Inertia is not a force, although it is often so called. If a force acts upon a body and puts it in motion, the effect of the force is stored in the body, and a second body, in stopping the first, will receive a blow equal in every respect to the original force, assuming that there has been no resistance of any kind to the motion of the first body.

It is dangerous for a person to jump from a fast-moving train, for the reason that, since his body has the same velocity as the train, it has the same force stored in it that would cause a body of the same weight to take the same velocity as the train, and the effect of a sudden stoppage is the same as the effect of a blow necessary to give the person that velocity.

By "bracing" himself and jumping in the same direction that the train is moving, and running, he brings himself gradually to rest, and thus reduces the danger. If a body is at rest, it must be acted upon by a force in order to be put in motion, and no matter how great the force may be, it can not be *instantly* put in motion.

The resistance thus offered to being put in motion is commonly, but erroneously, called the *resistance of inertia*. It should be called the *resistance due to inertia*.

1836. From the *second law*, it is seen that, if two or more forces act upon a body, their final effect upon the body will be in proportion to their magnitude and to the directions in which they act. Thus, if the wind is blowing due west, with a velocity of 50 miles per hour, and a ball is thrown due north with the same velocity, or 50 miles per hour, the wind will carry the ball just as far west as the force of the throw carried it north, and the combined effect will be to cause it to move northwest. The amount of departure from due north will be proportional to the force of the wind, and independent of the velocity due to the force of the throw.

1837. In Fig. 587, a ball *e* is supported in a cup, the bottom of which is attached to the lever *o* in such a manner that a movement of *o* will swing the bottom horizontally and allow the ball to drop. Another ball *b* rests in a horizontal groove that is provided with a slit in the bottom. A swinging arm is actuated by the spring *d* in such a manner that, when drawn back as shown and then released, it will strike the lever *o* and the ball *b* at the same time. This gives *b* an impulse in a horizontal direction and swings *o* so as to allow *e* to fall.

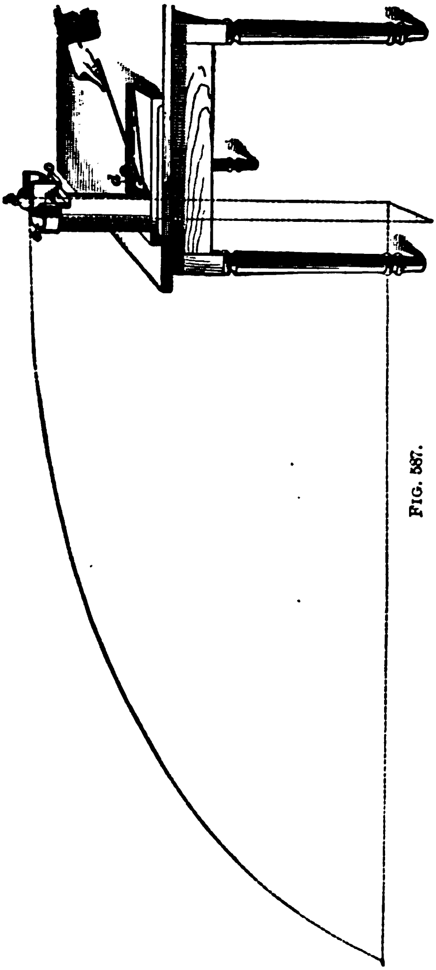


FIG. 587.

On trying the experiment, it is found that *b* follows a path shown by the curved dotted line, and reaches the floor at the same instant as *e*, which drops vertically. This shows that the force which gave the first ball its horizontal movement had no effect on the vertical force which compelled both balls to fall to the floor, the vertical force producing the same effect as if the horizontal force had not acted. The second law may also be stated as follows: *A force has the same effect in producing motion, whether it acts upon a body at*

rest or in motion, and whether it acts alone or with other forces.

1838. The *third law* states that action and reaction are equal and opposite. A man can not lift himself by his boot-straps, for the reason that he presses downwards with the same force that he pulls upwards; the downward reaction equals the upward action, and is opposite to it.

In springing from a boat, we must exercise caution, or the reaction will drive the boat from the shore. When we jump from the ground, we tend to push the earth from us, while the earth reacts and pushes us from it.

EXAMPLE.—Two men pull on a rope in opposite directions, each exerting a force of 100 pounds; what is the force which the rope resists?

SOLUTION.—Imagine the rope to be fastened to a tree, and one man to pull with a force of 100 pounds. The rope evidently resists 100 pounds. According to Newton's third law, the reaction of the tree is also 100 pounds. Now, suppose the rope to be slackened, but that one end is still fastened to the tree, and the second man to take hold of the rope near the tree, and pull with a force of 100 pounds, the first man pulling as before. The resistance of the rope is 100 pounds, as before, since the second man merely takes the place of the tree. *He is obliged to exert a force of 100 pounds to keep the rope from slipping through his fingers.* If the rope be passed around the tree and each man pulls an end with a force of 100 pounds in the same and parallel directions, the stress in the rope is 100 pounds, as before, but the tree must resist the pull of both men, or 200 pounds.

1839. A **force** may be represented by a line; thus, in Fig. 588, let A be the *point of application* of the force; let the length of the line $A B$ represent its *magnitude*, and let the arrow-head indicate the *direction* in which the force acts; then the line $A B$ fulfils the three conditions (see Art. **1831**), and the force is fully represented.

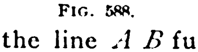


FIG. 588.

CENTER OF GRAVITY.

1840. The **center of gravity** of a body is that point at which the body may be balanced, or it is the point at which the whole weight of a body may be considered as concentrated.

1841. In a moving body, the line described by its center of gravity is always taken as the path of the body. In finding the distance that a body has moved, the distance that the center of gravity has moved is taken.

The definition of the center of gravity of a body may be applied to a system of bodies, if they are considered as being connected at their centers of gravity.

1842. If w and W, Fig. 589, be two bodies of known weights, their center of gravity will be at C. The point C may be readily determined, as follows:

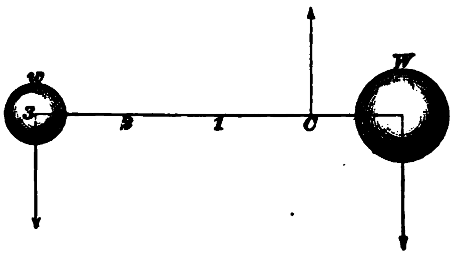


FIG. 589.

Rule.—*The distance of the common center of gravity from the center of gravity of the large weight is equal to the weight of the smaller body multiplied by the distance between the centers of gravity of the two bodies, and this product divided by the sum of the weights of the two bodies.*

Let w = weight of smaller body;

W = weight of larger body;

l = distance between centers of gravity of the two bodies;

l_1 = distance from the center of gravity of the two to the center of gravity of the larger body.

Then, $$l_1 = \frac{w\,l}{W + w}. \qquad \textbf{(93.)}$$

EXAMPLE.—In Fig. 589, $w = 10$ pounds, $W = 30$ pounds, and the distance between their centers of gravity is 36 inches; where is the center of gravity of both bodies situated?

SOLUTION.—Applying formula **93**,

$$l_1 = \frac{10 \times 36}{30 + 10} = 9 \text{ in.} =$$

distance of center of gravity from center of large weight. Ans.

1843. It is now very easy to extend this principle, to find the center of gravity of any number of bodies when their weights and the distances apart of their centers of gravity are known, by the following rule:

Rule.—*Find the center of gravity of two of the bodies, as W_1 and W_4, in Fig. 590, at C_1. Assume that the weight of both bodies is concentrated at C_1, and find the center of gravity of this combined weight C_1, and the weight of W_2 to be at C_2; then, find that the center of gravity of the combined weights of W_1, W_4, and W_2 (concentrated at C_2) and W_3 to be at C, and C will be the center of gravity of the four bodies.*

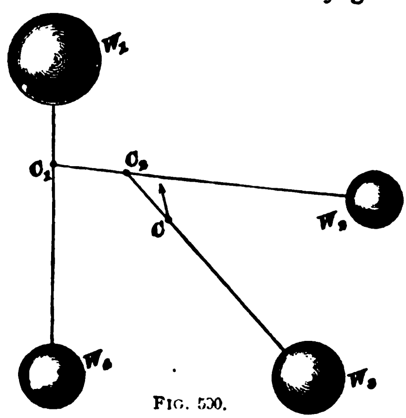


FIG. 590.

1844. To find the center of gravity of **any parallelogram:**

Rule.—*Draw the two diagonals, Fig. 591, and their point of intersection C will be the center of gravity.*

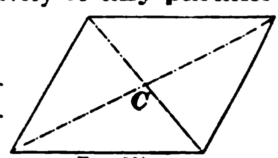


FIG. 591.

1845. To find the center of gravity of a **triangle,** as $A\ B\ C$, Fig. 592:

Rule.—*From any vertex, as A, draw a line to the middle point D of the opposite side $B\ C$. From one of the other vertexes, as C, draw a line to F, the middle point of the opposite side $A\ B$; the point of intersection O of these two lines is the center of gravity.*

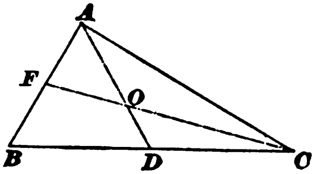


FIG. 592.

It is also true that the distance $D\ O = \frac{1}{3}\ D\ A$, and that

$FO = \frac{1}{3} FC$, and the center of gravity could have been found by drawing from any vertex a line to the middle point of the opposite side, and measuring back from that side $\frac{1}{3}$ of the length of the line.

1846. The center of gravity of **any regular plane figure** is the same as the center of the inscribed or circumscribed circle.

1847. To find the center of gravity of **any irregular plane figure** but of uniform thickness throughout, divide one of the parallel surfaces into triangles, parallelograms,

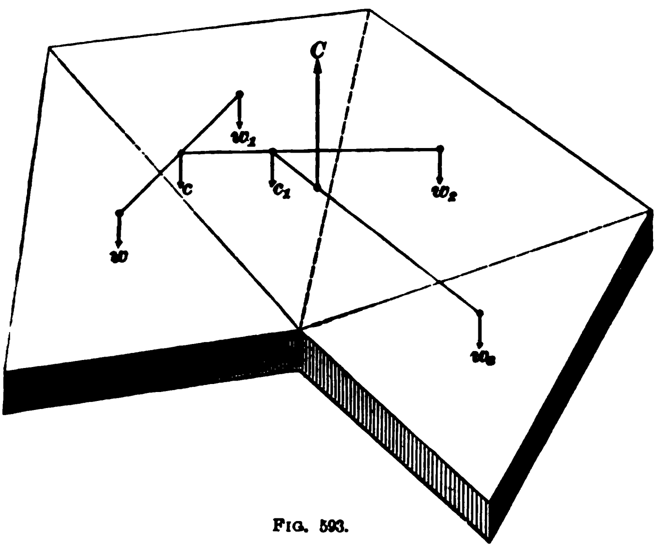


FIG. 593.

circles, ellipses, etc., according to the shape of the figure; find the area and center of gravity of each part separately, and combine the centers of gravity thus found as in the case of more than two bodies whose weights were known by the rule of Art. **1843,** except that the area of each part is used instead of their weights. See Fig. 593.

EXAMPLE.—Suppose that the two balls shown in Fig. 589 are 5 inches and 10 inches in diameter, and weigh 10 pounds and 80 pounds, respectively. If the distance between their centers is 40 inches, and

they are connected by a steel rod 1 inch in diameter, where is the center of gravity, taking the weight of a cubic inch of steel as .283 pound?

Solution.—The length of the rod $= 40 - \frac{5}{2} - \frac{10}{2} = 32\frac{1}{2}$ in. Its volume is $1^2 \times .7854 \times 32\frac{1}{2} = 25.53$ cu. in. $25.53 \times .283 = 7.22$ lb. The rod being straight, its center of gravity is in the middle at a distance of $\frac{32.5}{2} + \frac{5}{2} = 18\frac{3}{4}$ in. from the center of the smaller weight and $\frac{32.5}{2} + \frac{10}{2} = 21\frac{1}{4}$ in. from the center of the larger weight. Now, assuming the weight of the rod to be concentrated at its center of gravity, we have three weights of 10, 7.22, and 80 lb., all in a straight line, and the distances between them given, to find the center of gravity, or balancing-point, of the combination. We will first find the center of gravity of the two smaller weights by formula **93**.

$$l_1 = \frac{7.22 \times 18\frac{3}{4}}{10 + 7.22} = 7.86 \text{ in.} =$$

distance from the center of the 10-lb. weight. Considering both of the smaller weights to be concentrated at this point, we find the center of gravity of this combined weight and the large weight by the same formula:

$$40 - 7.86 = 32.14 \text{ in.} =$$

distance between the center of gravity of the two small weights and the center of gravity of the 80-lb. weight. Applying formula **93**,

$$l_1 = \frac{17.22 \times 32.14}{80 + 17.22} = 5.693 \text{ in.} =$$

distance from the center of the 80-lb. weight. Ans.

1848. Center of Gravity of a Solid.—In a body free to move, the center of gravity will lie in a vertical plumb-line

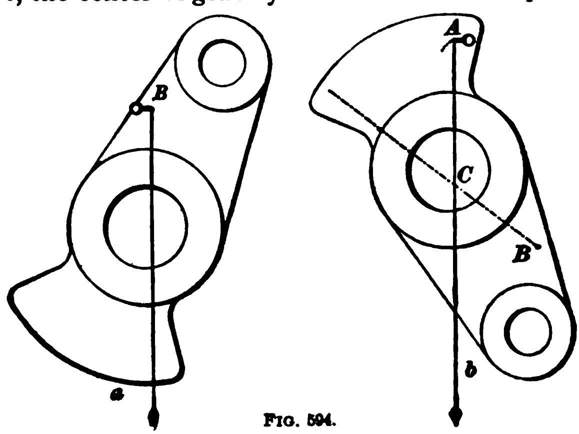


Fig. 594.

drawn through the point of support. Therefore, to find the position of the center of gravity of an irregular solid, as the crank, Fig. 594, suspend it at some point, as B, so that it will move freely. Drop a plumb-line from the point of suspension, and mark its direction. Suspend the body at another point, as A, and repeat the process. The intersection C of the two lines will be directly over the center of gravity.

Since the center of gravity depends wholly upon the shape and weight of a body, it may be without the body; for example, the center of gravity of a circular ring is the same as the center of the circumference of the ring.

EXAMPLES FOR PRACTICE.

1. A spherical shell has a wrought-iron handle attached to it. The shell is 10 inches in diameter, and weighs 20 pounds. The handle is 1¼ inches in diameter, and the distance from the center of the shell to the end of the handle is 4 feet. Where is the center of gravity? Take the weight of a cubic inch of wrought iron as .278 pound.
Ans. 13.612 in. from center of shell.

2. The distance between the centers of two bodies is 51 inches. The weights of the bodies being 20 and 73 pounds, where is the center of gravity? Ans. 10.968 in. from the center of large weight.

3. A hollow engine piston weighs 275 pounds, and is 3¼ inches thick. Assuming the piston-rod to be straight throughout its entire length, and to weigh 140 pounds, at what point will the piston and rod balance, if the length of the rod is 73 inches from the face of the piston? Consider the weight of the piston to be concentrated at its center.
Ans. 11.15 in., nearly, from face of piston.

4. Weights of 5, 9, and 12 pounds lie in one straight line, in the order named. Distance from the 5-pound weight to the 9-pound weight is 22 inches, and from the 9-pound weight to the 12-pound weight is 18 inches. Where is the center of gravity?
Ans. 13.923 in. from 12-pound weight.

SIMPLE MACHINES.

THE LEVER AND WHEEL AND AXLE.

1849. A **lever** is a bar capable of being turned about a pivot, or point, as in Figs. 595 to 597.

The object W to be lifted is called the **weight**; the force used P is called the **power**; and the point or pivot F is called the **fulcrum**.

That part of the lever between the weight and the fulcrum, or Fb, is called the **weight arm,** and the part between the power and the fulcrum, or Fc, is called the **power arm.**

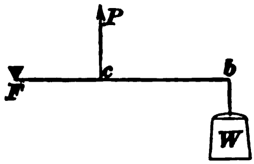


FIG. 595.

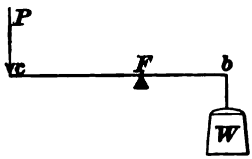


FIG. 596.

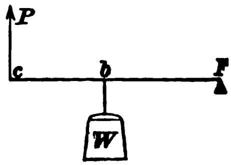


FIG. 597.

1850. In order that the lever shall be in equilibrium (balance), *the power multiplied by the power arm must equal the weight multiplied by the weight arm;* that is, $P \times Fc$ must equal $W \times Fb$.

If F be taken as the center of a circle, and arcs be described through b and c, it will be seen that, if the weight arm is moved through a certain angle, the power arm will move through the same angle. Since, in the same or equal angles, the lengths of the arcs are proportional to the radii with which they were described, it is seen that the power arm is proportional to the distance through which the power moves, and the weight arm is proportional to the distance through which the weight moves.

Hence, instead of writing $P \times Fc = W \times Fb$, we might have written it $P \times$ distance through which P moves $= W \times$ distance through which W moves. This is the general law of all machines, and can be applied to any mechanism, from the simple lever up to the most complicated arrangement. Stated in the form of a rule, it is as follows:

Rule.—*The power multiplied by the distance through which it moves equals the weight multiplied by the distance through which it moves.*

In the above rule, it will be noticed that there are four requirements necessary for a complete knowledge of the lever, viz., the power (or force), the weight, the power arm (or distance through which the power moves), and the weight

arm (or distance through which the weight moves). If any three are given, the fourth may be found by letting x represent the requirement which is to be found, and multiplying the power by the power arm and the weight by the weight arm; then, dividing the product of the two known numbers by the number by which x is multiplied, the result will be the requirement which was to be found.

EXAMPLE.—If the weight arm of a lever is 6 inches long, and the power arm is 4 feet long, how great a weight can be raised by a force of 20 pounds at the end of the power arm?

SOLUTION.—In this example, the weight is unknown; hence, representing it by x, we have, after reducing the 4 ft. to inches, $20 \times 48 = 960$ = power multiplied by the power arm, and $x \times 6$ = weight multiplied by the weight arm. Dividing the 960 by 6, the result is 160 lb., the weight. Ans.

If the distance through which the power or weight moved had been given instead of the power arm or weight arm, and it were required to find the power or weight, the process would have been exactly the same, using the given distance instead of the power arm or weight arm.

EXAMPLE.—If, in the above example, the weight had moved $2\frac{1}{2}$ inches, how far would the power have moved?

SOLUTION.—In this example, the distance through which the power moves is required. Let x represent the distance. Then, $20 \times x$ = distance multiplied by power, and $2\frac{1}{2} \times 160 = 400$ = distance multiplied by the weight. Hence, $x = \frac{400}{20} = 20$ in. = distance through which the power arm moves. Ans.

The ratio between the weights and the power is $160 \div 20 = 8$. The ratio between the distance through which the weight moves and the distance through which the power moves is $2\frac{1}{2} \div 20 = \frac{1}{8}$. This shows that while a force of 1 pound can raise a weight of 8 pounds, the 1-pound weight must move through 8 times the distance that the 8-pound weight does. It will also be noticed that the ratio of the lengths of the two arms of the lever is also 8, since $48 \div 6 = 8$.

1851. The law which governs the straight lever also governs the bent lever, but care must be taken to determine

the true lengths of the lever arms, which are in every case *the perpendicular distances from the fulcrum to the line of direction of the weight or power.*

Thus, in Figs. 598 to 601, Fc in each case represents the

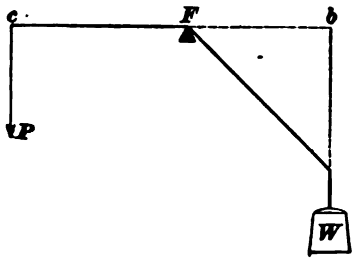


FIG. 598.

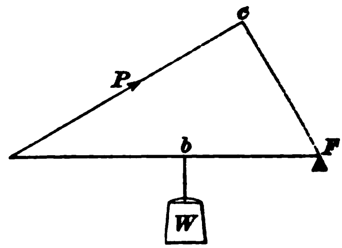


FIG. 599.

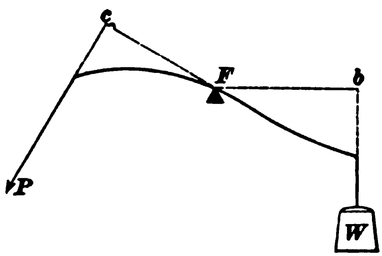


FIG. 600.

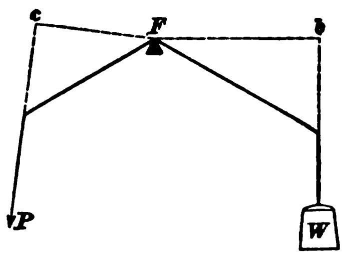


FIG. 601.

power arm, and Fb the weight arm. The following formula applies to any lever, straight or bent:

Let P = power;
W = weight;
a = perpendicular distance of line of direction of power from fulcrum = power arm;
b = perpendicular distance of line of direction of weight from fulcrum = weight arm.

Then, $$Pa = Wb. \qquad \textbf{(94.)}$$

1852. A **compound lever** is a series of single levers arranged in such a manner that when a power is applied to the first, it is communicated to the second, and from this to the third, and so on.

Fig. 602 shows a compound lever. It will be seen that, when a power is applied to the first lever at P, it will be communicated to the second lever at P, from this to the third lever at P, and thus raise the weight W.

The weight which the power of the first lever could raise acts as the power of the second, and the weight which this could raise through the second lever acts as the power of the third lever, and so on, no matter how many single levers make up the compound lever.

In this case, as in every other, the power multiplied by the distance through which it moves equals the weight multiplied by the distance through which it moves.

Hence, if we move the P end of the lever, say 4 inches,

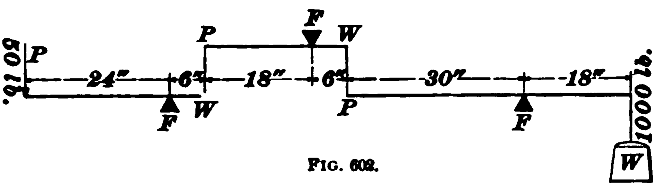


Fig. 602.

and the W end moves $\frac{1}{5}$ of an inch, we know that the ratio between P and W is the same as the ratio between 4 and $\frac{1}{5}$, that is, 1 to 20, and, hence, that 10 pounds at P would balance 200 pounds at W, without measuring the lengths of the different lever arms. If the lengths of the lever arms are known, the ratio between P and W may be readily obtained from the following rule:

Rule.—*The continued product of the power and each power arm equals the continued product of the weight and each weight arm.*

Let $a_1, a_2, a_3 \ldots\ldots =$ power arms of compound lever;
$b_1, b_2, b_3 \ldots\ldots =$ weight arms of compound lever.

Then,

$$P \times a_1 \times a_2 \times a_3 \times \ldots\ldots = W \times b_1 \times b_2 \times b_3 \times \ldots\ldots \quad \textbf{(95.)}$$

Example.—If, in Fig. 602, $PF = 24$ inches, 18 inches, and 30 inches, respectively, and $WF = 6$ inches, 6 inches, and 18 inches, respectively, how great a force at P would it require to raise 1,000 pounds at W? What is the ratio between W and P?

SOLUTION.—Let x represent the power; then, according to formula **95**, $x \times 24 \times 18 \times 30 = 12{,}960\,x$. $1{,}000 \times 6 \times 6 \times 18 = 648{,}000$.

$$x = \frac{648{,}000}{12{,}960} = 50 \text{ lb. Ans.}$$

$$1{,}000 \div 50 = 20 = \text{ratio of } W \text{ to } P. \text{ Ans.}$$

1853. The **wheel and axle** consists of *two cylinders of different diameters, rigidly connected*, so that they turn together about a common axis, as in Fig. 603. Then, as

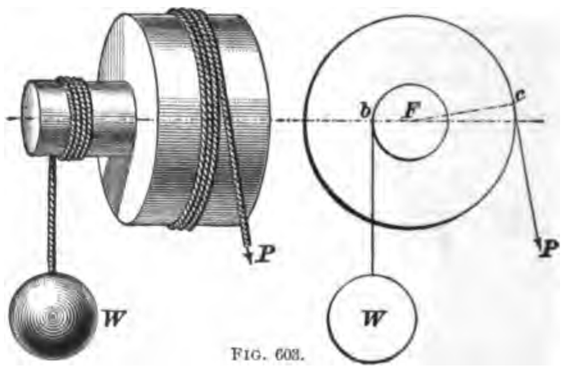


FIG. 603.

before, $P \times$ distance through which it moves $= W \times$ distance through which it moves; and, since these distances are proportional to the radii of the power cylinder and weight cylinder, $P \times F\,c = W \times F\,b$.

It is not necessary that an entire wheel be used; an arm, projection, radius, or anything which the power causes to revolve in a circle may be considered as the wheel. Consequently, if it is desired to hoist a weight with a windlass, Fig. 604, the power is applied to the handle of the crank, and the distance between the center line of the crank handle and the axis of the drum corresponds to the radius of the wheel.

FIG. 604.

EXAMPLE.—If the distance between the center line of the handle and the axis of the drum, in Fig. 604, is 18 inches, and the diameter of the drum

is 6 inches, what force will be required at P to raise a load of 300 pounds?

SOLUTION.—$P \times (18 \times 2) = 300 \times 6$, or $P = 50$. Ans.

EXAMPLES FOR PRACTICE.

1. The lever of a safety-valve is of the form shown in Fig. 595, where the force is applied at a point between the fulcrum and the weight lifted. If the distance from the fulcrum to the valve is $5\frac{1}{4}$ inches, and from the fulcrum to the weight is 42 inches, what total force is necessary to raise the valve, the weight being 78 pounds and the weight of valve and lever being neglected? Ans. 595.64 lb.

2. If, in Fig. 602, $PF = 10$, 12, 14, and 16 inches, respectively, and $WF = 2$, 3, 4, and 5 inches, respectively, (*a*) how great a weight can a force of 20 pounds raise? (*b*) What is the ratio between W and P? (*c*) If P moves 4 inches, how far will W move?

Ans. $\begin{cases} (a)\ 4{,}480 \text{ lb.} \\ (b)\ 224. \\ (c)\ \frac{1}{56} \text{ in.} \end{cases}$

3. A windlass is used to hoist a weight. If the diameter of the drum on which the rope winds is 4 inches, and the distance from the center of the handle to the axis of the drum is 14 inches, how great a weight can a force of 32 pounds applied to the handle raise? Ans. 224 lb.

PULLEYS AND GEARS.

FIXED AND MOVABLE PULLEYS.

1854. A **pulley** is a wheel turning on an axle, over which a cord, chain, or band is passed in order to transmit the force through the cord, chain, or band.

Pulleys are often used for hoisting or raising loads, in which case the frame which supports the axle of the pulley is called the **block**.

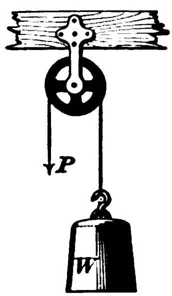


FIG. 605.

1855. A **fixed pulley** is one whose block is not movable (see Fig. 605). In this case, if the weight W be lifted by pulling down P, the other end of the cord W will evidently move the same distance upwards that P moves downwards; hence, P must equal W.

1856. A **movable pulley** is one whose block is movable, as in Fig. 606. One end of the cord is fastened to the

beam, and the weight is suspended from the pulley, the other end of the cord being drawn up by the application of a force P. A little consideration will show that if P moves through a certain distance, say 1 foot, W will move through *half* that distance, or 6 inches; hence, a pull of 1 pound at P will lift 2 pounds at W.

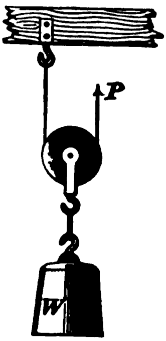


FIG. 606.

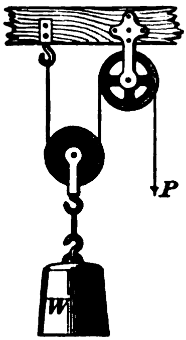


FIG. 607.

The same would also be true if the free end of the cord were passed over a *fixed pulley*, as in Fig. 607, in which case the fixed pulley merely changes the direction in which P acts, so that a weight of 1 pound hung on the free end of the cord will balance 2 pounds hung from the *movable pulley*.

1857. A combination of pulleys, as shown in Fig. 608, is sometimes used. In this case, there are three movable and three fixed pulleys, and the amount of movement of W, owing to a certain movement of P, is readily found.

It will be noticed that there are *six parts* of the rope, not counting the free end; hence, if the movable block be lifted 1 foot, P remaining in the same position, there will be 1 foot of slack in each of the six parts of the rope, or *six feet* in all. Therefore, P would have to move 6 feet in order to take up this slack, or P moves 6 times as far as W. Hence, 1 pound at P will support 6 pounds at W, since the *power multiplied by the distance through which it moves equals the weight multiplied by the distance through which it moves.* It will also be noticed that there are three movable pulleys, and that $3 \times 2 = 6$.

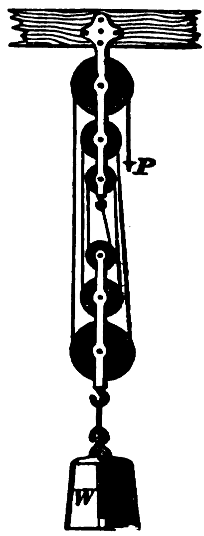


FIG. 608.

1858. Law of Combination of Pulleys.—*In any combination of pulleys where one continuous rope is used, a load on the free end will balance a weight on the movable block as many times as great as itself as there are parts of the rope supporting the load—not counting the free end.*

The above law is good, whether the pulleys are side by side, as in the ordinary block and tackle, or whether they are arranged as in the figure.

EXAMPLE.—In a block and tackle having five movable pulleys, how great a force must be applied to the free end of the rope to raise 1,250 pounds?

SOLUTION.—Since there are five movable pulleys, there must be 10 parts of the rope to support them. Hence, according to the above law, a force applied to the free end will support a load 10 times as great as itself, or the force $= \frac{1,250}{10} = 125$ lb. Ans.

PULLEYS FOR TRANSMISSION OF POWER.

1859. Pulleys for the transmission of power by belts may be divided into two principal classes: (1) The solid

FIG. 609.

FIG. 610.

pulley shown in Fig. 609, in which the hub, arms, and rim are one entire casting. (2) The split pulley shown in Fig. 610, which is cast in halves.

This last style of pulley is more readily placed upon and removed from the shaft than the solid pulley. Pulleys are generally cast in halves or parts when they are more than 6 feet in diameter; this is done on account of shrinkage strain in large pulley castings, which renders them liable to crack as a result of unequal cooling of the metal.

1860. Crowning.—In Fig. 611 is shown a section of the rim of a pulley that has crowning, or, in other words, whose diameter is larger at the center of the face than at its edges. This is done to prevent the belt from running off the pulley. The amount of crowning given to pulleys varies from $\frac{3}{16}$ to $\frac{1}{2}$ an inch per foot of width of the pulley face.

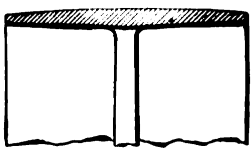


FIG. 611.

1861. Balanced Pulleys.—All pulleys which rotate at high speeds should be balanced. If they are not, the centrifugal force which is generated by the pulley's rotation is greater on one side than on the other, and it will cause the pulley shaft to vibrate and shake. Pulleys should run true, so that the strain or tension of the belt is equal at all parts of the revolution, thus making the transmitting power equal. The smoother the surface of a pulley, the greater is its driving power.

The transmitting power of a pulley can be increased by covering the face of the pulley with a leather or rubber band; this increases the driving power about one-quarter.

1862. The pulley that imparts motion to the belt is called the **driver**; that which receives the motion is called the **driven.**

The revolutions of any two pulleys over which a belt is run vary in an inverse proportion to their diameters; consequently, if a pulley of 20 inches in diameter is driven by one of 10 inches in diameter, the 20-inch pulley will make one revolution while the 10-inch pulley makes two revolutions, or they are in the ratio of 2 to 1.

1863. To find the diameter of the driving pulley, when the diameter of the driven pulley and the number of revolutions per minute of each are given:

Rule.—*The diameter of the driving pulley equals the product of the diameter and number of revolutions of the driven pulley, divided by the number of revolutions of the driving pulley.*

Let D = diameter of the driver;
d = diameter of the driven;
N = number of revolutions of the driver;
n = number of revolutions of the driven.

NOTE.—The words revolutions per minute are frequently abbreviated to R. P. M.

Then, $$D = \frac{d\,n}{N}. \qquad \textbf{(96.)}$$

EXAMPLE.—The driving pulley makes 100 revolutions per minute; the driven pulley makes 75 revolutions per minute, and is 18 inches in diameter; what is the diameter of the driving pulley?

SOLUTION.—Substituting in formula **96**, we have

$$D = \frac{18 \times 75}{100} = 13\tfrac{1}{2} \text{ in. Ans.}$$

1864. The diameter and number of revolutions per minute of the driving pulley being given, to find the diameter of the driven pulley, which must make a given number of revolutions per minute:

Rule.—*The diameter of the driven pulley equals the product of the diameter and number of revolutions of the driving pulley, divided by the number of revolutions of the driven pulley.*

That is, $$d = \frac{D\,N}{n}. \qquad \textbf{(97.)}$$

EXAMPLE.—The diameter of the driver is $13\tfrac{1}{2}$ inches, and makes 100 revolutions per minute; what must be the diameter of the driven to make 75 revolutions per minute?

SOLUTION.—Substituting in formula **97**, we have

$$d = \frac{13\tfrac{1}{2} \times 100}{75} = 18 \text{ in. Ans.}$$

1865. To find the number of revolutions per minute of the driven pulley, its diameter and the diameter and number of revolutions per minute of the driving pulley being given:

Rule.—*The number of revolutions of the driven pulley is equal to the product of the diameter and number of revolutions of the driver, divided by the diameter of the driven pulley.*

That is, $$n = \frac{DN}{d}. \qquad (98.)$$

EXAMPLE.—The driver is $13\frac{1}{2}$ inches in diameter, and makes 100 revolutions per minute; how many revolutions will the driven make in one minute, if it is 18 inches in diameter?

SOLUTION.—Substituting in formula **98**, we have

$$n = \frac{13\frac{1}{2} \times 100}{18} = 75 \text{ R. P. M.} \quad \text{Ans.}$$

1866. To find the number of revolutions per minute of the driving pulley, its diameter and the diameter and number of revolutions per minute of the driven pulley being given:

Rule.—*The number of revolutions of the driving pulley is equal to the product of the diameter and number of revolutions of the driven pulley, divided by the diameter of the driving pulley.*

That is, $$N = \frac{dn}{D}. \qquad (99.)$$

EXAMPLE.—The driven pulley is 18 inches in diameter, and makes 75 revolutions per minute; how many revolutions will the driver make in one minute, if it is $13\frac{1}{2}$ inches in diameter?

SOLUTION.—Substituting in formula **99**, we have

$$N = \frac{18 \times 75}{13\frac{1}{2}} = 100 \text{ R. P. M.} \quad \text{Ans.}$$

WHEELWORK.

1867. Wheelwork.—A combination of wheels and axles, as in Fig. 612, is called a **train.** The wheel in a train, to which motion is imparted from a wheel on another shaft by such means as a belt or gearing, is called the **driven wheel** or **follower;** the wheel which imparts the motion is called the **driver.**

It will be seen that the wheel and axle bears the same

relation to the train that the simple lever does to the compound lever. Letting D_1, D_2, D_3, etc., represent the diam-

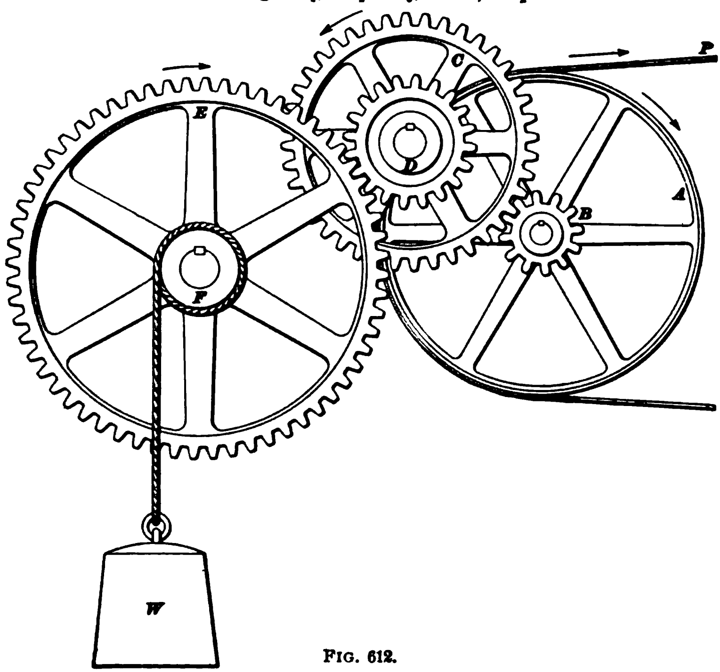


FIG. 612.

eters of the driven wheels and d_1, d_2, d_3, etc., the diameters of the drivers, we have the following

Rule.—*The continued product of the power and the radii of the driven wheels equals the continued product of the weight, the radius of the drum that moves the weight, and the radii of the drivers.*

This rule gives rise to the following formulas:

$$P = \frac{W \times d_1 \times d_2 \times d_3 \times \ldots}{D_1 \times D_2 \times D_3 \times \ldots}. \quad (100.)$$

$$W = \frac{P \times D_1 \times D_2 \times D_3 \times \ldots}{d_1 \times d_2 \times d_3 \times \ldots}. \quad (101.)$$

EXAMPLE.—The radius of the pulley A is 20 inches, of C, 15 inches, and of E, 24 inches; and the radius of the drum F is 4 inches, of the pinion D, 5 inches, and of the pinion B, 4 inches. How great a weight will a force of 1 pound at P raise?

SOLUTION.—Using formula **101**, we have

$$W = \frac{1 \times 20 \times 15 \times 24}{4 \times 5 \times 4} = \frac{7,200}{80} = 90 \text{ lb. Ans.}$$

If the weight W were raised 1 inch, P would fall 90 inches, or P would have to move 90 inches to raise W 1 inch. *Whenever there is a gain in power without a corresponding increase in the initial force, there is a loss in speed;* this is true of any machine.

In the last example, if P were to move the entire 90 inches in one second, W would move only 1 inch in one second.

1868. Instead of using the diameter or radius of a gear, the number of teeth may be used when computing the weight which can be raised, or the velocity, as in the last example.

EXAMPLE.—Assume that the radius of the pulley A, Fig. 612, is 40 inches, and that of F is 12 inches. The number of teeth in B is 9; in c, 27; in D, 12, and in E, 36. If the weight to be lifted is 1,800 pounds, how great a force at P is it necessary to apply to the belt?

SOLUTION.—Let P represent the force (power); then, by formula **100**,

$$P = \frac{1,800 \times 12 \times 9 \times 12}{40 \times 27 \times 36} = \frac{2,332,800}{38,880} = 60 \text{ lb. Ans.}$$

GEAR-WHEELS.

1869. A wheel that is provided with teeth to mesh with similar teeth upon another wheel is called a **gear-wheel,** or **gear.** In Fig. 613 is shown a **spur-gear.** On spur-gears, the teeth are always parallel to the axis of the wheel, or to its shaft.

FIG. 613.

1870. In Fig. 614 is shown a pair of **bevel-gears** in mesh, of which one is smaller than the other. When both are of the same diameter, they are called **miter-gears.**

In Fig. 615 is shown a pair

of miter-gears in mesh. It is obvious that the angle which the teeth of these gears make with the axis of the shaft must be 45°.

FIG. 614.

1871. In Fig. 616 is shown a revolving screw, or worm, as it is called, in gear; it is used to transmit motion from one shaft to another at right angles to it.

As the worm is nothing else than a screw, each revolution given to the worm will rotate the worm-wheel a distance

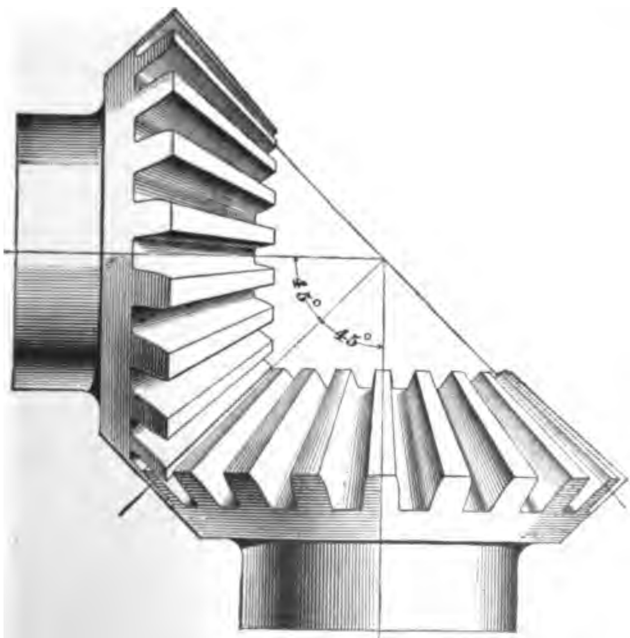


FIG. 615.

equal to its pitch; consequently, if there are 40 teeth in the worm-wheel, a single-threaded worm will have to make 40 revolutions in order to turn the wheel once.

1872. In Fig. 617 is shown a section of a rack and pinion, both having epicycloidal teeth. The arc *C C* represents part of the **pitch circle;** it is on the pitch circle that all the teeth are laid out. The diameter of a gear or worm-wheel is always taken as the diameter of this circle, unless otherwise specially stated as "diameter over all," or "diameter at the root," etc.

FIG. 616.

The **pitch** of the teeth of the gear-wheel is the distance from the edge of one tooth to the corresponding edge of the following tooth measured on the pitch circle; it is marked *pitch* in the figure.

The length of the tooth of a gear-wheel is .7 of its pitch, .4 of it, called the **root,** being below or within the pitch circle, and .3 of it, called the **addendum,** being above or

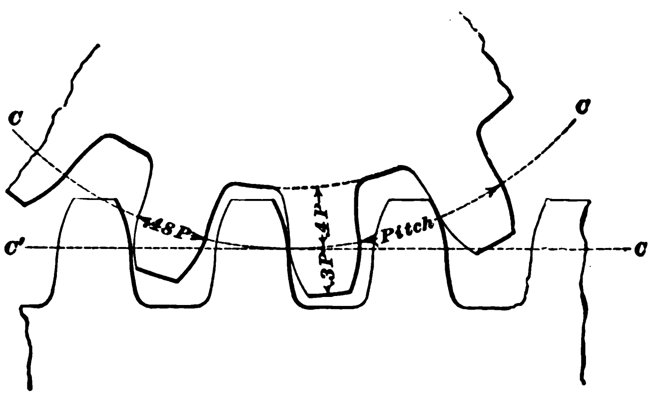


FIG. 617.

without the pitch circle. Thus, if the pitch of the teeth of a gear-wheel is 2 inches, the length of the teeth below the pitch circle is $2 \times .4 = .8$ of an inch; and the length of

the teeth above the pitch circle is $2 \times .3 = .6$ of an inch. Consequently, we have only to multiply the pitch by .4 to obtain the length of the teeth below the pitch circle, and by .3 to obtain the length of the teeth above the pitch circle. The thickness of the teeth of a cast gear-wheel equals $.48 \times P$, that is, .48 of the pitch; therefore, the thickness of the above teeth is $.48 \times 2$, or .96 of an inch.

A rack may be considered as a gear-wheel rolled out so as to make the pitch circle a straight line, as $C' C''$. The teeth of racks are proportioned by the same rules as those of gear-wheels.

1873. For the purpose of calculating the pitch, diameter, number of teeth, etc., of gear-wheels, the following rules are given:

To find the pitch diameter of a gear-wheel in inches, when the pitch and number of teeth are given:

Rule.—*The pitch diameter is equal to the product of the pitch and number of teeth, divided by 3.1416.*

Let $P =$ pitch;
$T =$ number of teeth;
$D =$ pitch diameter of the wheel.

Then, $$D = \frac{PT}{3.1416}. \qquad \textbf{(102.)}$$

EXAMPLE.—What is the diameter of the pitch circle of a gear-wheel which has 75 teeth, and whose pitch is 1.675 inches?

SOLUTION.—Substituting in formula **102**, we have

$$D = \frac{1.675 \times 75}{3.1416} = 40 \text{ in. Ans.}$$

1874. To find the number of teeth in a gear-wheel, when the diameter and pitch are given:

Rule.—*The number of teeth is equal to the product of 3.1416 and the diamcter, divided by the pitch.*

That is, $$T = \frac{3.1416\, D}{P}. \qquad \textbf{(103.)}$$

EXAMPLE.—The diameter of a gear-wheel is 40 inches, and the pitch of the teeth is 1.675 inches; how many teeth are there in the wheel?

SOLUTION.—Substituting in formula **103**, we have

$$T = \frac{3.1416 \times 40}{1.675} = 75 \text{ teeth. Ans.}$$

1875. To find the pitch of a gear-wheel, when the diameter and the number of teeth are given:

Rule.—*The pitch of the teeth is equal to the product of 3.1416 and the diameter, divided by the number of teeth.*

That is, $$P = \frac{3.1416\,D}{T}. \qquad \textbf{(104.)}$$

EXAMPLE.—The diameter of a gear-wheel is 40 inches, and it has 75 teeth; what is the pitch of the teeth?

SOLUTION.—Applying formula **104**, we have

$$P = \frac{3.1416 \times 40}{75} = 1.675 \text{ in. Ans.}$$

1876. The forms of teeth used in ordinary practice are the epicycloidal and involute.

Fig. 617 shows the epicycloidal form, which is composed of two different curves; namely, that curve from the pitch

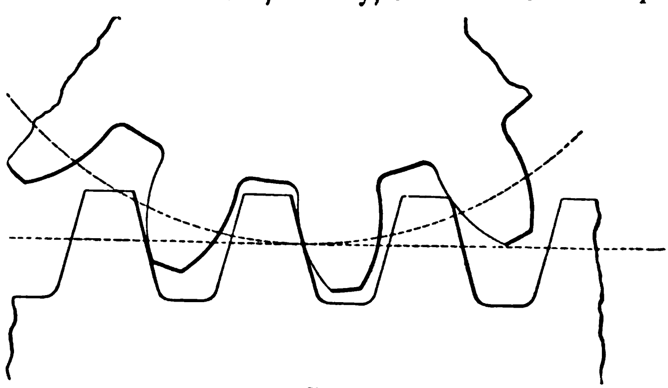


FIG. 618.

circle to the top of the tooth is an epicycloid, and that from the pitch circle to the bottom of the tooth is a hypocycloid.

In gear-wheels where this form of tooth is employed, their pitch circles must run tangent to one another.

1877. In Fig. 618 is shown the involute form of teeth, or teeth having but one curve. The outlines of the teeth shown in the rack are formed of straight lines.

Involute teeth have two great advantages over epicycloidal teeth: (1) They are stronger for the same pitch, as they are thicker at the root. (2) They may be spread apart so that their pitch circles do not run tangent to one another without practically affecting the perfect action of the teeth.

1878. To calculate the number of teeth or speed of one of two gear-wheels which are to gear together:

Let R = number of revolutions per minute of the driver;
r = number of revolutions per minute of the driven;
T = number of teeth in the driver;
t = number of teeth in the driven.

Rule.—*The number of teeth in the driver equals the product of the number of teeth and number of revolutions of the driven, divided by the number of revolutions of the driver.*

That is, $$T = \frac{t\,r}{R}. \qquad \textbf{(105.)}$$

Example.—The driven has 27 teeth, and will make 66 revolutions per minute; if the driver makes 99 revolutions per minute, how many teeth are there in the driver?

Solution.—Substituting in formula **105**, we have

$$T = \frac{27 \times 66}{99} = 18 \text{ teeth. Ans.}$$

1879. The number of revolutions per minute of the driver and driven, and the number of teeth in the driver being given, to find the number of teeth in the driven:

Rule.—*The number of teeth in the driven is equal to the product of the number of teeth and revolutions per minute of the driver, divided by the number of revolutions per minute of the driven.*

That is, $$t = \frac{T\,R}{r}. \qquad \textbf{(106.)}$$

EXAMPLE.—The driver has 24 teeth, and makes 99 revolutions per minute, and the driven must make 66 revolutions per minute; how many teeth must there be in the driven?

SOLUTION.—Substituting in formula **106**, we have

$$t = \frac{24 \times 99}{66} = 36 \text{ teeth. Ans.}$$

1880. The number of teeth in the driver and driven. and the number of revolutions per minute of the driver being given, to find the number of revolutions per minute of the driven:

Rule.—*The number of revolutions per minute of the driven is equal to the product of the number of teeth and number of revolutions of the driver, divided by the number of teeth of the driven.*

That is, $$r = \frac{TR}{t}. \qquad \textbf{(107.)}$$

EXAMPLE.—There are 18 teeth in the driver, and it makes 60 revolutions per minute; how many revolutions per minute will the driven make if it has 30 teeth?

SOLUTION.—Applying formula **107**, we have

$$r = \frac{18 \times 60}{30} = 36 \text{ R. P. M. Ans.}$$

1881. The number of teeth in the driver and driven, and the number of revolutions per minute of the driven being given, to find the number of revolutions per minute of the driver:

Rule.—*The number of revolutions of the driver is equal to the product of the number of teeth and revolutions of the driven, divided by the number of teeth of the driver.*

That is, $$R = \frac{tr}{T}. \qquad \textbf{(108.)}$$

EXAMPLE.—If there are 42 teeth in the driven, and if it makes 66 revolutions per minute, how many revolutions per minute will the driver make if it has 18 teeth?

SOLUTION.—Using formula **108**, we have

$$R = \frac{42 \times 66}{18} = 154 \text{ R. P. M. Ans.}$$

EXAMPLE.—In Fig. 619, the crank-shaft makes 60 revolutions per minute; the governor pulley is 4 inches in diameter, and the bevel-

gear on the governor pulley-shaft has 19 teeth; the bevel-gear which meshes with it and drives the governor has 30 teeth. The governor is to make 95 revolutions per minute; what should be the size of the pulley on the crank-shaft?

SOLUTION.—First determine the number of revolutions of the 4-inch pulley in order that the governor shall turn 95 times per minute. Applying formula **108**, we have $R = \frac{30 \times 95}{19} = 150$ revolutions of gear on pulley-shaft = revolutions of governor pulley. Now, applying formula **96**, we have $D = \frac{4 \times 150}{60} = 10$ in. = diameter of the pulley on the crank-shaft. Ans.

EXAMPLE.—In Fig. 619, the fly-wheel is 8 feet in diameter and drives a 5-foot pulley on the main shaft. A 14-inch pulley on the main shaft drives a 16-inch pulley on the countershaft. A 12-inch pulley on the

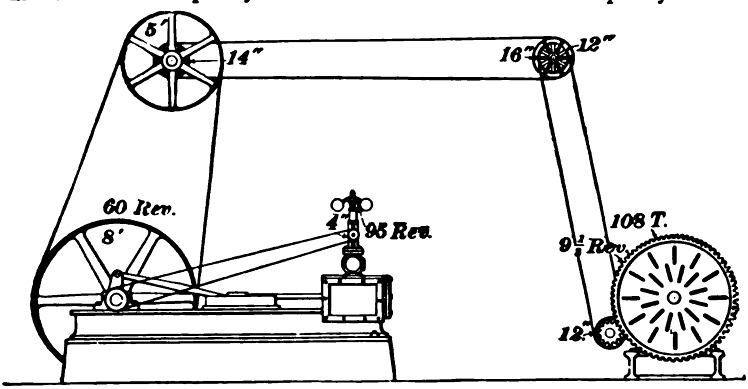


FIG. 619.

countershaft drives a 12-inch pulley on a shaft on which is a pinion that meshes into a large gear, attached to the face-plate of a large lathe, which has 108 teeth. How many teeth must the pinion have in order that the face-plate may make 9⅓ revolutions per minute?

SOLUTION.—Applying formula **98**, to find the revolutions per minute of the main shaft, $n = \frac{8 \times 60}{5} = 96$ R. P. M. Applying formula **98** again to find the revolutions of the countershaft, $n = \frac{14 \times 96}{16} = 84$ R. P. M.; and again to find revolutions of the pulley which turns the small gear, $n = \frac{12 \times 84}{12} = 84$ R. P. M. Applying formula **105**, we have $T = \frac{108 \times 9\frac{1}{3}}{84} = 12$ teeth in pinion or driver. Ans.

1882. Horsepower of Gears.—To find the horsepower which can be safely transmitted by gears whose face, or breadth of tooth, is from $2\frac{1}{2}$ to 3 times their pitch:

Rule.—*The horsepower which can be safely transmitted equals the continued product of the square of the pitch, the velocity in feet per minute, and .01.*

Let p = the pitch;

s = circumferential speed of a point on the pitch circle in feet per minute.

Then, $$\text{H. P.} = .01\, s\, p^2. \qquad \textbf{(109.)}$$

EXAMPLE.—What horsepower can be safely transmitted by a gear whose pitch diameter is 66.84 in., pitch $1\frac{3}{4}$ in., and which makes 60 R. P. M.?

SOLUTION.—The velocity which is to be used when applying formula **108** is the circumferential speed of a point on the pitch circle. Hence, $66.84 \times 3.1416 = 209.98$ in. = circumference of pitch circle = $\frac{209.98}{12}$ ft. $\frac{209.98}{12} \times 60 = 1{,}049.9$ = velocity in ft. per min.

Now, applying formula **109**, H. P. $= .01 \times 1{,}049.9 \times 1.75^2 = 32.15$ horsepower. Ans.

1883. When measuring bevel-gears, the diameter of the largest pitch circle should be taken, as D, Fig. 620.

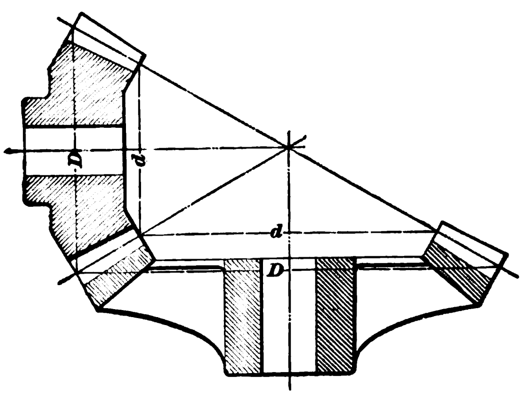


FIG. 620.

When calculating their horsepower, use the small or inner diameter, as d, Fig. 620. Either diameter may be used when calculating the revolutions per minute or number of

teeth by formulas **102** to **108,** but if the inner or outer diameter of one gear be used, the corresponding diameter of the other gear which meshes with it must also be used.

EXAMPLES FOR PRACTICE.

1. The driving pulley makes 110 R. P. M., and is 21 inches in diameter; what should be the size of the driven in order to make 385 R. P. M.? Ans. 6 in.

2. The main shaft of a certain shop makes 120 R. P. M. It is desired to have the countershaft make 150 R. P. M. There are on hand pulleys of 16, 24, 28, 35, and 38 inches in diameter. Can two of these be used, or must a new pulley be ordered?
Ans. Use the 28-inch and the 35-inch pulley.

3. The pinion (driver) makes 174 R. P. M. and follower makes 24 R. P. M.; how many teeth must the pinion have if the follower has 87 teeth? Ans. 12 teeth.

4. If an engine fly-wheel is 66 inches in diameter and makes 160 R. P. M., what must be the diameter of the pulley on the main shaft to make 128 R. P. M.? Ans. $82\frac{1}{2}$ in.

5. What is the pitch diameter of a gear whose pitch is $1\frac{1}{4}$ inches and has 28 teeth? Ans. 11.14 in.

6. How many teeth are there in a gear whose pitch is .7854 inch and which is 23 inches in diameter? Ans. 92 teeth.

7. What is the pitch of a gear whose diameter is 20.372 inches and which has 128 teeth? Ans. $\frac{1}{2}$ in.

8. In a train of gears the drivers have 16, 30, 24, and 18 teeth, respectively; the followers have 12, 24, 36, and 40 teeth, respectively. If the first driver makes 80 R. P. M., how many R. P. M. will the last follower make? Ans. 40 R. P. M.

9. What horsepower can be safely transmitted by a gear whose pitch is $2\frac{1}{4}$", pitch diameter 44.66", and which makes 80 R. P. M.?
Ans. 42.24 H. P.

THE INCLINED PLANE AND WEDGE.

1884. An **inclined plane** is a slope, or a flat surface, making an angle with a horizontal line.

Three cases may arise in practice with the inclined plane:

1. When the power acts parallel to the plane, as in Fig. 621.

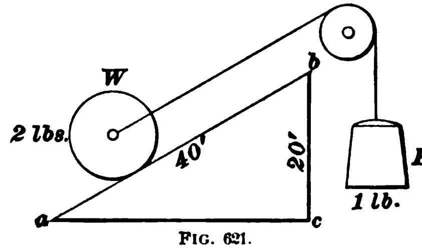


FIG. 621.

2. When the power acts parallel to the base, as in Fig. 622.

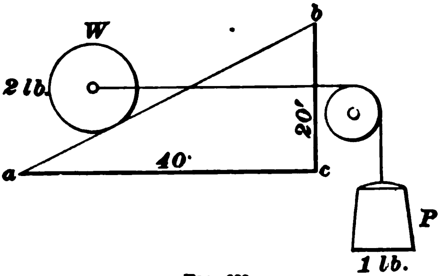


FIG. 622.

3. When the power acts at an angle to the plane, or to the base, as in Fig. 623.

1885. In Fig. 621, the relation existing between the power and the weight is easily found. The weight ascends a distance equal to $c\ b$, or the height of the inclined plane, while the power descends through a distance equal to $a\ b$, or the length of the inclined plane. Therefore, the *power multiplied by the length of the inclined plane equals the weight multiplied by the height of the inclined plane.* Hence, if the length $a\ b = 40$ feet, and the height $c\ b = 20$ feet, $W \times 20 = P \times 40$, or 1 pound at P will balance 2 pounds at W.

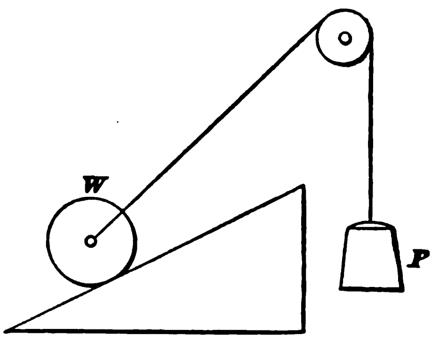


FIG. 623.

In Fig. 622, the power is supposed to act parallel to the base, for any position of W; therefore, while W is moving from the level $a\ c$ to b, or through the height $c\ b$ of the inclined plane, P will move through a distance equal to the length of the base $a\ c$. Hence, when the power acts parallel to the base, $W \times$ *height of the inclined plane* $= P \times$ *length of base.*

If the length of the base is 40 feet, and the height of the inclined plane is 20 feet, $W \times 20 = P \times 40$, and 1 pound at P will balance 2 pounds at W.

For Fig. 623 no rule can be given. The ratio of the power to the weight must be determined by trigonometry for every position of W.

1886. The **wedge** is a movable inclined plane, and is used for moving a great weight a short distance. A common method of moving a heavy body is shown in Fig. 624.

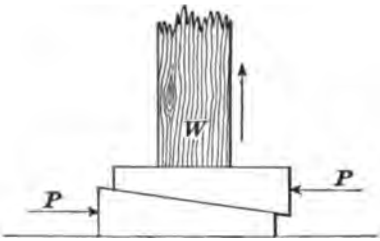


FIG. 624.

Simultaneous blows of equal force are struck on the heads of the wedges, thus raising the weight *W*. The laws for wedges are the same as for Case 2 of the inclined plane.

THE SCREW.

1887. A **screw** is a cylinder with a helical groove winding around its circumference. This helix is called the *thread* of the screw. The distance that a point on the helix is drawn back or advanced in one turn of the screw is called the *pitch* of the screw.

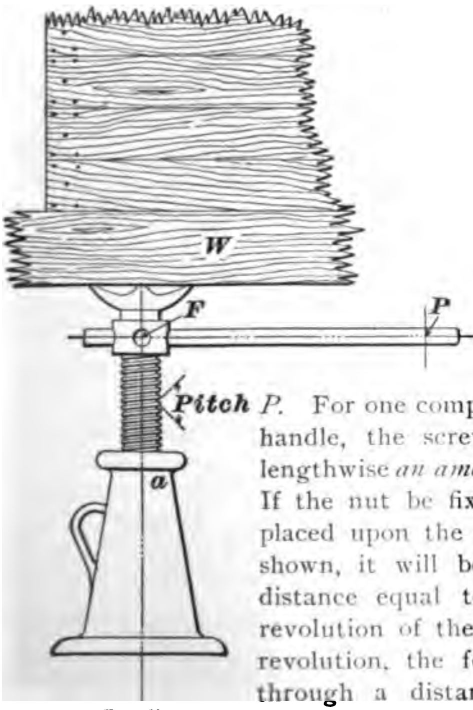


FIG. 625.

1888. The screw in Fig. 625 is turned in a *nut a*, by means of a force applied at the end of the handle *P*. For one complete revolution of the handle, the screw will be advanced lengthwise *an amount equal to the pitch.* If the nut be fixed, and a weight be placed upon the end of the screw, as shown, it will be raised vertically a distance equal to the pitch, by one revolution of the screw. During this revolution, the force at *P* will move through a distance equal to the

circumference, whose radius is PF. Hence, $W \times$ pitch of thread $= P \times$ circumference of P.

Let W = weight lifted;
P = force applied to handle;
p = pitch of screw;
R = radius of circle of force P.

Then,
$$W = \frac{6.2832\,PR}{p}. \qquad \textbf{(110.)}$$

$$P = \frac{p\,W}{6.2832\,R}. \qquad \textbf{(111.)}$$

Rule.—*Represent the required force or weight by x; multiply the force by the distance from the center of the screw to the point of the handle where the force is applied; multiply this product by 2 and by 3.1416, and place the result equal to the weight multiplied by the pitch. Divide the product of the known numbers by the number or product of the numbers by which x is multiplied, and the result will be the value of x.*

Single-threaded screws of less than 1-inch pitch are generally classified by the number of threads they have in 1 inch of their length. In such cases, *one inch divided by the number of threads equals the pitch;* thus, the pitch of a screw that has 8 threads per inch is $\frac{1}{8}$, one of 32 threads per inch is $\frac{1}{32}$, etc.

Example.—It is desired to raise a weight by means of a screw having 5 threads per inch. The force applied is 40 pounds at a distance of 14 inches from the center of the screw; how great a weight can be raised?

Solution.—The pitch is $\frac{1}{5}$ inch. Using formula **110,**

$$W = \frac{6.2832 \times 40 \times 14}{\frac{1}{5}} = 17{,}592.96 \text{ lb. Ans.}$$

1889. Velocity Ratio.—The ratio of the distance that the power moves to the distance which the weight moves on account of the movement of the power is called the **velocity ratio.**

Thus, if the power is moving 12 inches while the weight is moving 1 inch, the velocity ratio is 12 to 1, or 12; that is, P moves 12 times as fast as W.

If the velocity ratio is known, the weight which any machine can raise equals the *power multiplied by the velocity ratio.* If the velocity ratio is 8.7 to 1, or 8.7, $W = 8.7 \times P$, since $W \times 1 = P \times 8.7$.

NOTE.—In all of the preceding cases, including the last, friction has been neglected.

FRICTION.

1890. Friction is the resistance that a body meets from the surface on which it moves.

1891. The **ratio** between the *resistance* to the motion of a body due to friction and the *perpendicular* pressure between the surfaces is called the **coefficient of friction.**

If a weight W, as in Fig. 626, rests upon a horizontal plane, and has a cord fastened to it passing over a pulley a,

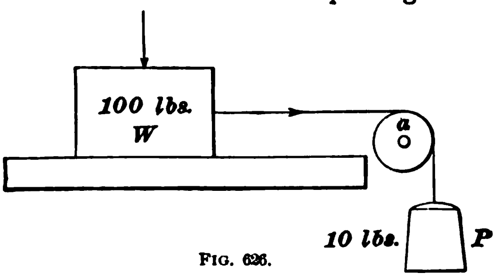


FIG. 626.

from which a weight P is suspended, then, if P is just sufficient to start W, the ratio of P to W, or $\frac{P}{W}$, is the *coefficient of friction* between W and the surface it slides upon.

The weight W is the perpendicular pressure, and P is the force necessary to overcome the resistance to the motion of W due to friction.

If $W = 100$ pounds and $P = 10$ pounds, the coefficient of friction for this particular case would be $\frac{P}{W} = \frac{10}{100} = .1$.

1892. Laws of Friction:

I. *Friction is directly proportional to the perpendicular pressure between the two surfaces in contact.*

II. *Friction is independent of the extent of the surfaces in contact when the total perpendicular pressure remains the same.*

III. *Friction increases with the roughness of the surfaces.*

IV. *Friction is greater between surfaces of the same material than between those of different materials.*

V. *Friction is greatest at the beginning of motion.*

VI. *Friction is greater between soft bodies than between hard ones.*

VII. *Rolling friction is less than sliding friction.*

VIII. *Friction is diminished by polishing or lubricating the surfaces.*

1893. Law I shows why the friction is so much greater on journals after they begin to heat than before. The heat causes the journal to expand, thus increasing the pressure between the journal and its bearing, and, consequently, increasing the friction.

Law II states that no matter how small the surface may be which presses against another, if the perpendicular pressure is the same, the friction will be the same. Therefore, large surfaces are used where possible, not to reduce the friction, but to reduce the wear and diminish the liability of heating.

For instance, if the perpendicular pressure between a journal and its bearing is 10,000 pounds, and the coefficient of friction is .2, the amount of friction is $10,000 \times .2 = 2,000$ pounds. Suppose that one-half the area of the surface of the journal is 80 square inches, then the amount of friction for each square inch of bearing is $2,000 \div 80 = 25$ pounds.

If half the area of the surface had been 160 square inches, the friction would have been the same, that is, 2,000 pounds; but the friction per square inch would have been $2,000 \div 160 = 12\frac{1}{2}$ pounds, just one-half as much as before, and the wear and liability to heat would be one-half as great also.

TABLE 31.

COEFFICIENTS OF FRICTION.

Description of Surfaces in Contact.	Disposition of Fibers.	State of the Surfaces.	Coefficient of Friction
Oak on Oak	Parallel	Dry	.48
Oak on Oak	Parallel	Soaped	.16
Wrought Iron on Oak	Parallel	Dry	.62
Wrought Iron on Oak	Parallel	Soaped	.21
Cast Iron on Oak	Parallel	Dry	.49
Cast Iron on Oak	Parallel	Soaped	.19
Wrought Iron on Cast Iron	....	Slightly Unctuous	.18
Wrought Iron on Bronze	....	Slightly Unctuous	.18
Cast Iron on Cast Iron	....	Slightly Unctuous	.15

1894. The power which is required to raise a weight, or overcome an equal resistance in any machine, is thus always *greater than this weight or resistance divided by the velocity ratio of the machine.*

Thus, if there were no friction, a machine whose velocity ratio were 5 would, by an application of a force of 100 pounds, raise a weight of 500 pounds.

Now, suppose that the friction in the machine is equivalent to the application of a force of 10 pounds; then, it would take a force of 110 pounds to raise the weight of 500 pounds.

If, in the above illustration, friction were neglected, 110 pounds $\times$ 5 = 550 pounds, or the weight that 110 pounds would raise; but, owing to the frictional resistance, it only raised 500 pounds. Therefore, we have for the ratio between the two $\frac{500}{550} = .91$. That is,

$$500 : 550 :: .91 : 1.$$

1895. Efficiency.—This ratio between the weight actually raised and the power multiplied by the velocity ratio is called the **efficiency of the machine.**

For example, if the weight actually raised by a machine, say a screw, is 1,600 pounds, and the power multiplied by the velocity ratio is 2,400 pounds, the efficiency of this machine is $\frac{1,600}{2,400} = .66\frac{2}{3}$, or $66\frac{2}{3}\%$.

EXAMPLE.—In a machine having a combination of pulleys and gears, the velocity ratio of the whole is 9.75. A force of 250 pounds just lifts a weight of 1,626 pounds. What is the efficiency of the machine?

SOLUTION.—Efficiency $= \frac{1,626}{250 \times 9.75} = .6671$, or 66.71%. Ans.

1896. Since the total amount of friction varies with the load, it follows that the efficiency will also vary for different loads.

If the efficiency of a machine is known, the force actually required to raise a given load may be found by dividing the load by the product of the velocity ratio of the machine and the efficiency. Thus, if a certain machine has a velocity ratio of 10.6, and its efficiency is 60%, the force which must actually be applied to raise a load of 840 pounds is $840 \div 10.6 \times .60 = 840 \div 6.36 = 132.1$ pounds, nearly. If there had been no losses through friction, etc., the force required would have been $840 \div 10.6 = 79.25$ pounds, nearly.

If the efficiency is known, the weight which a certain force will raise may be found by multiplying together the force, velocity ratio, and the efficiency. Thus, if a certain machine has a velocity ratio of $6\frac{1}{2}$ and an efficiency of 7[illegible] a force of 140 pounds will raise a weight of $140 \times 6\frac{1}{2} \times .7$[illegible] 709.8 pounds.

When finding the force necessary to overcome the friction the *perpendicular pressure* on the surface considered must always be taken. Thus, to find the greatest perpendicular pressure on the guides of a steam-engine due to the action of the piston-rod and connecting-rod on the cross-head multiply the total piston pressure by the length of the crank and divide by the length of the connecting-rod. This res[illegible]

multiplied by the proper coefficient of friction, will give the friction of the cross-head on the guides.

EXAMPLE.—An engine whose piston is 16 inches in diameter carries a steam pressure of 80 pounds per square inch. If the crank is 12 inches long and the connecting-rod is 66 inches long, what is the perpendicular pressure on the guides? The coefficient of friction for this case being 12%, what force will be required to overcome the friction?

SOLUTION.—Pressure on piston $= 16^2 \times .7854 \times 80 = 16{,}085$ lb. $\frac{16{,}085 \times 12}{66} = 2{,}924.55$ lb. = perpendicular pressure. Ans. $2{,}924.55 \times .12 = 350.95$ lb. = force required to overcome the friction. Ans.

EXAMPLES FOR PRACTICE.

1. How great a force must be applied to the free end of the rope of a block and tackle which has four movable pulleys, to raise a weight of 746 pounds? Ans. $93\frac{1}{4}$ lb.

2. An inclined plane is 30 feet long and 7 feet high; what force is required to roll a barrel of flour weighing 196 pounds up the plane, friction being neglected? Ans. $45.7\frac{1}{3}$ lb.

3. The distance from the axis of a screw to the point on the handle where the force is applied is twelve inches. The screw has 8 threads per inch. What force is necessary to raise a weight of 1,248 pounds? Ans. 2.07 lb., nearly.

4. In example 3, what should be the length of the handle to raise a weight of 5,400 pounds by the application of a force of 20 pounds? Ans. 5.371 inches, nearly.

5. What is the velocity ratio (*a*) in example 3? (*b*) in example 4?

Ans. $\begin{cases} (a)\ 603, \text{ nearly.} \\ (b)\ 270. \end{cases}$

6. An engine-piston is 24 inches in diameter. If the steam pressure is 93 pounds per square inch; the length of the connecting-rod, 8 feet 4 inches; the length of crank 20 inches, and coefficient of friction 14%, (*a*) what is the perpendicular pressure on the guides? (*b*) the force required to overcome the friction?

Ans. $\begin{cases} (a)\ 8{,}414.46 \text{ lb.} \\ (b)\ 1{,}178 \text{ lb.} \end{cases}$

CENTRIFUGAL FORCE.

1897. If a body be fastened to a string and whirled so as to give it a circular motion, there will be a pull on the string which will be greater or less according as the velocity increases or decreases. The cause of this pull on the string will now be explained.

F. II.—27

Suppose that the body is revolved horizontally, so that the action of gravity upon it will always be the same. According to the first law of motion, a body put in motion tends to move in a straight line unless acted upon by some other force, causing a change in the direction. When the body moves in a circle, the force that causes it to move in a circle instead of a straight line is exactly equal to the tension of the string. If the string were cut, the pulling force that draws it away from the straight line would be removed, and the body would then "fly off at a tangent;" that is, it would move in a straight line tangent to the circle, as shown in Fig. 627.

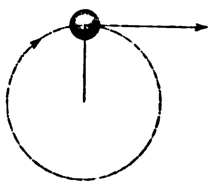


FIG. 627.

1898. Since, according to the third law of motion, every action has an equal and opposite reaction, we call that force which acts as an equal and opposite force to the pull of the string the **centrifugal force,** and it acts *away* from the center of motion.

The other force, or the pull of the string towards the center, is called the **centripetal force,** and it acts *towards* the center of motion. It is evident that these two forces, acting in opposite directions, tend to pull the string apart, and, if the velocity be increased sufficiently, the string will break. It is also evident that no body can revolve without generating centrifugal force.

The value of the centrifugal force, expressed in pounds, of any revolving body is calculated by the following rule:

Rule.—*The centrifugal force is equal to the continued product of .00034, the weight of the body in pounds, the radius in feet (taken as the distance between the center of gravity of the body and the center about which it revolves), and the square of the number of revolutions per minute.*

Let F = centrifugal force in pounds;

W = weight of revolving body in pounds;

R = radius in feet of circle described by center of gravity of revolving body;
N = revolutions per minute of revolving body.

Then, $F = .00034\ W R N^2$. **(112.)**

In calculating the centrifugal force of fly-wheels, it is the usual practice to consider the rim of the wheel only, and not take the arms and hub of the wheel into account. In this case, R would be taken as the *distance between the center of the rim and the center of the shaft.*

EXAMPLE.—A crank-pin weighing 65 pounds revolves in a circle whose radius is 21 inches. The number of revolutions is 180. What is the centrifugal force set up by the pin?

SOLUTION.— 21 in. = $1\frac{3}{4}$ ft. Using formula **112**,

$$F = .00034 \times 65 \times 1\tfrac{3}{4} \times 180^2 = 1{,}253.07 \text{ lb. Ans.}$$

SPECIFIC GRAVITY.

1899. The **specific gravity of a body** is the ratio between its weight and the weight of a like volume of water.

Since gases are so much lighter than water, it is usual to take the specific gravity of a gas as the ratio between the weight of a certain volume of the gas and the weight of the same volume of air.

EXAMPLE.—A cubic foot of cast iron weighs 450 pounds; what is its specific gravity, a cubic foot of water weighing 62.5 pounds?

SOLUTION.— $\frac{450}{62.5} = 7.2$. Ans.

1900. The specific gravities of different bodies are given in the tables of Specific Gravities; hence, if it is desired to know the weight of a body that can not be conveniently weighed, *calculate its cubical contents, and multiply the specific gravity of the body by the weight of a like volume of water, remembering that a cubic foot of water weighs 62.5 pounds.*

EXAMPLE.—How much will 3,214 cubic inches of cast iron weigh? Take its specific gravity as 7.21.

SOLUTION.—Since 1 cubic foot of water weighs 62.5 pounds, 3,214 cubic inches weigh $\frac{3,214}{1,728} \times 62.5 = 116.25$ pounds.

$$116.25 \times 7.21 = 838.16 \text{ pounds. Ans.}$$

EXAMPLE.—What is the weight of a cubic inch of cast iron?

SOLUTION.— $\frac{62.5}{1,728} \times 7.21 = .2608$ pound. Ans.

NOTE.—One cubic foot of pure distilled water at a temperature of 39.2° Fahrenheit weighs 62.42 pounds, but the value usually taken in making calculations is 62½ pounds.

EXAMPLE.—What is the weight in pounds of 7 cubic feet of oxygen?

SOLUTION.—One cubic foot of air weighs .08073 lb. (see table of Specific Gravities), and the specific gravity of oxygen is 1.1056 compared with air; hence, $.08073 \times 1.1056 \times 7 = .62479$ pound, nearly. Ans.

EXAMPLES FOR PRACTICE.

1. The balls of a steam-engine governor each weigh 5 pounds. If they revolve in a circle whose diameter is 14 inches at the rate of 80 revolutions per minute, what is the centrifugal force of each ball?
Ans. 6.347 lb., nearly.

2. If a cubic foot of a certain alloy weighs 678 pounds, what is its specific gravity?
Ans. 10.848.

3. What is the weight of (*a*) 12.4 cubic inches of lead? (*b*) of steel? (*c*) of aluminum?
Ans. (*a*) 5.0964 lb. (*b*) 3.5216 lb. (*c*) 1.116 lb.

4. The specific gravity of an alloy of lead and zinc is 8.26; what is the weight of a cubic foot?
Ans. 516.25 lb.

WORK AND ENERGY.

1901. **Work** *is the overcoming of resistance continually occurring along the path of motion.* Mere motion is not work, but if a body in motion constantly overcomes a resistance, it does work.

1902. *The* **measure of work** *is one pound raised vertically one foot*, and is called **one foot-pound.** All work is measured by this standard. A horse going up hill does an amount of work equal to his own weight, plus the weight of the wagon and contents, plus the frictional resistances reduced to an equivalent weight, multiplied by the vertical

height of the hill. Thus, if the horse weighs 1,200 pounds, the wagon and contents 1,200 pounds, and the frictional resistances equal 400 pounds, then, if the vertical height of the hill is 100 feet, the work done is equal to $(1,200 + 1,200 + 400) \times 100 = 280,000$ foot-pounds.

Rule.—*To find the work, multiply the force (or resistance) by the distance through which it acts. If the work consists in raising a weight, it is equal to the product of the weight multiplied by the vertical height of the lift.*

The *total* amount of work is independent of time, whether it takes one minute or one year in which to do it, but in order to compare the work done by different machines with a common standard, time must be considered. If one machine does a certain amount of work in 10 minutes, and another machine does exactly the same amount of work in 5 minutes, the second machine can do twice as much work as the first in the same time.

1903. The common standard to which all work is reduced is the *horsepower*, which is abbreviated H. P. *One horsepower is equal to 33,000 foot-pounds per minute; in other words, it is the work done in raising 33,000 pounds vertically one foot in one minute, or in raising 1 pound vertically 33,000 feet in one minute, or any combination that will, when multiplied together, give 33,000 foot-pounds in one minute.*

Thus, the work done in raising 110 pounds vertically 5 feet in one second is a horsepower, for, since in one minute there are 60 seconds, $110 \times 5 \times 60 = 33,000$ foot-pounds in one minute.

EXAMPLE.—If the coefficient of friction is .3, how many horsepower will be required to draw a load of 10,000 pounds on a level surface, a distance of one mile in one hour?

SOLUTION.— $10,000 \times .3 = 3,000$ pounds = the force necessary to overcome the resistance (resistance of the air is neglected). One mile = 5,280 feet; one hour = 60 minutes. Therefore, $\frac{5,280}{60} = 88$ feet per minute.

Work done = force multiplied by the space $= 3,000 \times 88 = 264,000$ foot-pounds per minute.

Horsepower $= \frac{264,000}{33,000} = 8$. Ans.

1904. Energy is a term used to express *the ability of an agent to do work.* Work can not be done without motion, and the work that a moving body is capable of doing in being brought to rest is called the **kinetic energy** of the body.

Kinetic energy means the actual visible energy of a body in motion. The work which a moving body is capable of doing in being brought to rest is exactly the same as the kinetic energy developed by it in falling in a vacuum through a height sufficient to give it the same velocity.

Rule.—*The kinetic energy of a moving body in foot-pounds equals its weight in pounds multiplied by the square of its velocity in feet per second, and divided by 64.32.*

Let W = weight of body in pounds;
v = velocity in feet per second;
K = kinetic energy in foot-pounds.

Then, $$K = \frac{Wv^2}{64.32}. \qquad \textbf{(113.)}$$

If a weight is raised to a certain height, a certain amount of work is done equal to the product of the weight and the vertical height. If a weight is suspended at a certain height and allowed to fall, it will do the same amount of work in foot-pounds that was required to raise the weight to the height through which it fell.

EXAMPLE.—If a body weighing 25 pounds falls from a height of 100 feet, how much work can it do?

SOLUTION.—Work = $Wh = 25 \times 100 = 2{,}500$ foot-pounds. Ans.

It requires the same amount of work or energy to stop a body in motion within a certain time as it does to give it that velocity in the same time.

EXAMPLE.—A body weighing 50 pounds has a velocity of 100 feet per second; what is its kinetic energy?

SOLUTION.—Applying formula **113**,

$$K = \frac{Wv^2}{64.32} = \frac{50 \times 100^2}{64.32} = 7{,}773.63 \text{ foot-pounds. Ans.}$$

EXAMPLE.—In the last example, how many horsepower will be required to give the body this amount of kinetic energy in 3 seconds?

SOLUTION.— 1 H. P. = 33,000 pounds raised 1 foot in 1 minute. If 7,773.63 foot-pounds of work are done in 3 seconds, in 1 second there would be done $\frac{7,773.63}{3} = 2,591.21$ foot-pounds of work. One horse-power = 33,000 ft.-lb. per min. = $33,000 \div 60 = 550$ ft.-lb. per sec. The number of horsepower developed will be $\frac{2,591.21}{550} = 4.71$ H. P. Ans.

1905. Potential energy *is latent energy; it is the energy which a body at rest is capable of giving out under certain conditions.*

If a stone is suspended by a string from a high tower, it has potential energy. If the string is cut, the stone will fall to the ground, and during its fall its potential energy will change into kinetic energy, so that at the instant it strikes the ground its potential energy is wholly changed into kinetic energy.

At a point equal to one-half the height of the fall, the potential and kinetic energies are equal. At the end of the first quarter, the potential energy was $\frac{3}{4}$, and the kinetic energy $\frac{1}{4}$; at the end of the third quarter, the potential energy was $\frac{1}{4}$, and the kinetic energy $\frac{3}{4}$.

A pound of coal has a certain amount of potential energy. When the coal is burned, the potential energy is liberated and changed into kinetic energy in the form of heat. The kinetic energy of the heat changes water into steam, which thus has a certain amount of potential energy. The steam acting on the piston of an engine causes it to move through a certain space, thus overcoming a resistance, changing the potential energy of the steam into kinetic energy, and thus doing work.

Potential energy, *then, is the energy stored within a body, which may be liberated and produce motion, thus generating kinetic energy, and enabling work to be done.*

1906. The principle of **conservation of energy** teaches that energy, like matter, can never be destroyed. If a clock is put in motion, the potential energy of the spring is changed into kinetic energy of motion, which turns the wheels, thus producing friction.

The friction produces heat, which dissipates into the surrounding air, but still the energy is not destroyed—it merely exists in another form. The potential energy in coal was received from the sun in the form of heat ages ago, and has lain dormant for millions of years.

BELTS.

1907. A **belt** is a flexible connecting-band which drives a pulley by its frictional resistance to slipping at the surface of the pulley. Belts are most commonly made of leather or rubber, and united in long lengths by *cementing*, *riveting*, or *lacing*.

Belts are made *single* and *double*. A **single belt** is one composed of a single thickness of leather; a **double belt** is one composed of two thicknesses of leather cemented and riveted together the whole length of the belt.

1908. To Find the Length of a Belt.—In practice, the necessary length for a belt to pass around pulleys that are already in their position on a shaft is usually obtained by passing a tape-line around the pulleys; the stretch of the tape-line is allowed as that necessary for the belt. The lengths of open-running belts for pulleys not in position can be obtained as follows:

Rule.—*The length of a belt for open-running pulleys equals $3\frac{1}{4}$ times one-half the sum of the diameters of the pulleys plus 2 times the distance between the centers of the shafts.*

Let D = diameter of one pulley;
D_1 = diameter of other pulley;
L = distance between the centers of the shafts;
B = length of the belt.

Then, $$B = 3\tfrac{1}{4}\left(\frac{D + D_1}{2}\right) + 2L. \qquad \textbf{(114.)}$$

EXAMPLE.—The distance between the centers of two shafts is 9 feet 7 inches; the diameter of the large pulley is 36 inches, and the diameter of the small one is 14 inches; what is the necessary length of the belt?

SOLUTION.—Substituting in formula **114**, we have, since 9 feet 7 inches = 115 inches,

$$B = 8\tfrac{1}{4}\left(\frac{36 + 14}{2}\right) + 2 \times 115 = 311\tfrac{1}{4} \text{ in., or 25 ft. } 11\tfrac{1}{4} \text{ in.} \quad \text{Ans.}$$

1909. To find the width of a single leather belt that will transmit any given horsepower when equal pulleys are used:

Rule.—*The width of the belt in inches equals 800 times the horsepower to be transmitted divided by the speed of the belt in feet per minute.*

Let W = width of single belt in inches;
H = horsepower to be transmitted;
S = speed of belt in feet per minute.

Then, $$W = \frac{800\,H}{S}. \qquad \textbf{(115.)}$$

EXAMPLE.—What width of single leather belt is required to transmit 20 horsepower when equal pulleys are used and the speed is 1,600 feet per minute?

SOLUTION.—Substituting in formula **115**,

$$W = \frac{800 \times 20}{1{,}600} = 10 \text{ inches.} \quad \text{Ans.}$$

1910. To find the number of horsepower that a single leather belt will transmit, its width and speed being given:

Rule.—*The number of horsepower equals the product of the width in inches and the speed in feet per minute divided by 800.*

Or, $$H = \frac{WS}{800}. \qquad \textbf{(116.)}$$

EXAMPLE.—If a 16-inch single leather belt is to be run at a speed of 700 feet per minute, what horsepower will it transmit?

SOLUTION.—Substituting in formula **116**, we have

$$H = \frac{16 \times 700}{800} = 14 \text{ horsepower.} \quad \text{Ans.}$$

When the pulleys are of different diameter, the arc of contact must be considered. To find the number of degrees in the arc of contact, *multiply the length of belt in contact on the smaller pulley by 360, and divide the product by the*

circumference of the pulley, calculating the result to the nearest whole number. The quotient is the arc of contact.

Having found the arc of contact, *subtract it from 180° and multiply the result by 3. Add this last result to 800; the number thus obtained should be used instead of 800 in formulas* **115** *and* **116.**

EXAMPLE.—What should be the width of a single leather belt to transmit 25.24 horsepower at a speed of 1,500 feet per minute, the diameter of the smaller pulley being 24", and the belt having 30" of its length in contact with it?

SOLUTION.—Arc of contact $= \frac{30 \times 360}{24 \times 3.1416} = 143°$. $(180 - 143) \times 3 = 111$. $800 + 111 = 911$. Using formula **115,** and 911 instead of 800,

$$W = \frac{911 \times 25.24}{1,500} = 15.33'', \text{ say } 15\tfrac{1}{4}''. \quad \text{Ans.}$$

1911. To find the width of a double belt that will transmit the same horsepower as a given single belt, let W_1 represent the width of the double belt; then,

Rule.—*Multiply the width of a single belt that will transmit the same horsepower by* $\frac{2}{3}$.

Or, $$W_1 = \tfrac{2}{3} W. \qquad \textbf{(117.)}$$

EXAMPLE.—If a single leather belt is 15" in width and transmits 21.818 horsepower, what must be the width of a double belt to transmit the same horsepower?

SOLUTION.—Applying formula **117,**

$$W_1 = 15 \times \tfrac{2}{3} = 10 \text{ in.} = \text{width of double belt.} \quad \text{Ans.}$$

1912. Lacing Belts.—Many good methods of fastening the ends of belts are employed, but lacing is generally used, as it is flexible like the belt, and runs noiselessly over the pulleys.

When punching a belt for lacing, use an oval punch, the long diameter of the hole to be parallel with the side of the belt.

In a 3-inch belt, there should be four holes in each end, two in each row. In a 6-inch belt, seven holes, four in the row nearest the end. A 10-inch belt should have nine holes, five in the row nearest the end. The edges of the holes

should not be nearer than ¾ of an inch from the sides, and ⅞ of an inch from the ends of the belt. The second row should be at least 1¾ inches from the end.

Always begin to lace from the center of the belt, and take care to get the ends exactly in line. The lacing should not be crossed on the side of the belt that runs next to the pulley. Always run the hair side of the belt next to the pulley.

EXAMPLES FOR PRACTICE.

1. How many foot-pounds of work are required to overcome for 7 minutes the friction of the cross-head of an engine which has a stroke of 4 feet and makes 160 strokes per minute, if the coefficient of friction is 8% and the average perpendicular pressure is 12,460 pounds?

Ans. 4,465,664 ft.-lb.

2. In the above example, what horsepower is required?

Ans. 19.332 H. P.

3. A cannon-ball weighing 500 pounds is fired with a velocity of 1,600 feet per second; what is its kinetic energy?

Ans. 19,900,497.5 ft.-lb.

4. An open belt drives two pulleys which are respectively 42 inches and 20 inches in diameter and 23 feet apart between their centers; what should be the length of the belt? Ans. 652¼ in., or 54 ft. 4¼ in.

5. What width of single leather belting, which has 2 feet 9 inches contact on the small pulley, is required to transmit 10 horsepower at a speed of 1,500 feet per min.? Give width to nearest half inch. Diameter of small pulley, 26 inches. Ans. 6 in.

6. What should be the width of the main belt of a steam-engine to transmit 120 horsepower? The engine runs at 80 R. P. M., the band wheel is 8 feet in diameter, the belt is double and has a contact of 6 feet on the smaller pulley, which is 5 feet in diameter. Take the speed of the belt the same as that of a point on the circumference of the band-wheel. Ans. 36½ in.

7. A 26-inch double belt runs at a speed of 2,830 feet per min. and has a contact of 5 feet on the smaller pulley; what horsepower is it transmitting? Diameter of small pulley is 48 inches.

Ans. 121.15 H. P.

MECHANICS.

(PART 2.)

THE COMPOSITION OF FORCES.

1913. When two forces act upon a body at the same time but at different angles, their final result may be obtained as follows:

In Fig. 628, let A be the common *point of application* of the two forces, and let $A\ B$ and $A\ C$ represent the *magnitude* and *direction* of the forces. According to the second law of motion, the final effect of the movement due to these two forces would be the same, whether they acted singly or together. Suppose that the line $A\ B$ represents the distance that the force $A\ B$ would cause the body to move; similarly, that $A\ C$ represents the distance which the force $A\ C$ would cause the body to move when both forces were acting separately.

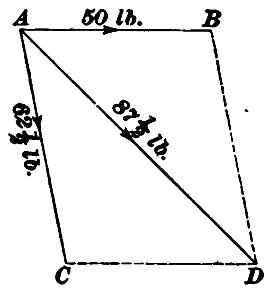


FIG. 628.

The force $A\ B$, acting alone, would carry the body to B; if the force $A\ C$ were now to act upon the body, it would carry it along the line $B\ D$, parallel to $A\ C$, to a point D, at a distance from B equal to $A\ C$. Join C and D; then, $C\ D$ is parallel to $A\ B$, and $A\ B\ D\ C$ is a parallelogram. Draw the diagonal $A\ D$. According to the second law of motion, the body will stop at D, whether the forces act separately or together, but if they act together, the path of the body will be along $A\ D$, the diagonal of the parallelogram. Moreover, the length of the line $A\ D$ represents the *magnitude* of a force, which, acting at A in the *direction* $A\ D$, would

cause the body to move from A to D; in other words, $A\,D$, measured to the same scale as $A\,B$ and $A\,C$, represents in *magnitude* and *direction* the combined effect of the two forces $A\,B$ and $A\,C$.

This line $A\,D$ is called the **resultant.** Suppose that the scale used was 50 pounds to the inch; then, if $A\,B = 50$ pounds, and $A\,C = 62\frac{1}{2}$ pounds, the length of $A\,B$ would be $\frac{50}{50} = 1$ inch, and the length of $A\,C$ would be $\frac{62.5}{50} = 1\frac{1}{4}$ inches. If $A\,D$, or the *resultant*, measures $1\frac{3}{4}$ inches, its *magnitude* would be $1\frac{3}{4} \times 50 = 87\frac{1}{2}$ pounds.

Therefore, a force of $87\frac{1}{2}$ pounds acting upon a body at A in the direction $A\,D$ will produce the same result as the combined effects of a force of 50 pounds acting in the direction $A\,B$, and a force of $62\frac{1}{2}$ pounds acting in the direction $A\,C$.

1914. The above method of finding the resulting action of two forces acting upon a body at a common point is correct, whatever may be their direction and magnitudes. Hence, to find the **resultant** of two forces when their common point of application, their direction, and magnitudes are known:

Rule.—*Assume a point, and draw two lines parallel to the directions of the lines of action of the two forces. With any convenient scale, measure off from the point of intersection (common point of application) distances corresponding to the magnitudes of the respective forces, and complete the parallelogram. From the common point of application, draw the diagonal of the parallelogram; this diagonal will be the resultant, and its direction will be away from the point of application. Its magnitude should be measured with the same scale that was used to measure the two forces.*

This method is called the **graphical method of the parallelogram of forces.**

1915. The principle of the parallelogram of forces is clearly shown in Fig. 629. $A\,B\,D\,C$ is a wooden frame, jointed to allow motion at its four corners. The length

$A B$ equals $C D$; that of $A C$ equals $B D$, and the corresponding adjacent sides are in the ratio of 2 to 3. Cords pass over the pulleys M and N, carrying weights W and w, of 90 and 60 pounds. The ratio between the weights equals the ratio of the corresponding adjacent sides. A weight V of 120 pounds is hung from the corner A.

When the frame comes to rest, the sides $A B$ and $A C$ lie

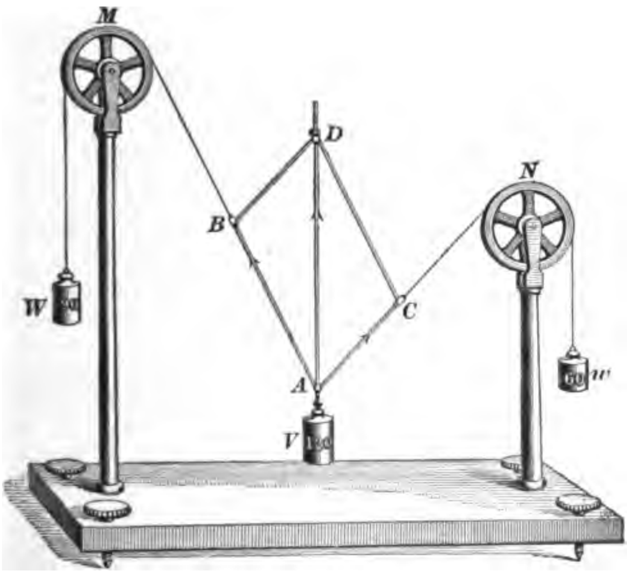


FIG. 629.

in the direction of the cords. These sides $A B$ and $A C$ are accurate graphic representations of the two forces acting upon the point A. It will be found that the diagonal $A D$ is vertical, and twice as long as $A C$; hence, since $A C$ represents a force of 60 pounds, $A D$ will represent a force of 2×60, or 120 pounds.

Thus, we see that the line $A D$ represents the *resultant* of the two forces $A B$ and $A C$; in other words, it represents the resultant of the two weights W and w. This resultant is equal and opposite to the vertical force, which is due to the weight of V.

Satisfactory results of this kind will be secured when we have the proportion

$$A B : A C = W : w.$$

EXAMPLE.—If two forces act upon a body at a common point, both acting away from the body, and the angle between them is 80°, what is the value of the resultant, the magnitude of the two forces being 60 pounds and 90 pounds, respectively ?

SOLUTION.—Draw two indefinite lines having an angle of 80° between them. With any convenient scale, say 10 pounds to the inch, measure off $A B = 60 \div 10 = 6$ inches, and $A C = 90 \div 10 = 9$ inches.

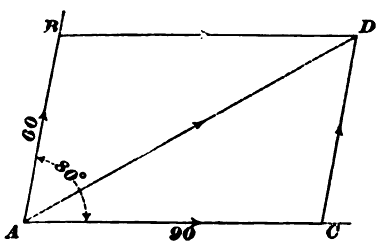


FIG. 630.

Through B, draw $B D$ parallel to $A C$, and through C, draw $C D$ parallel to $A B$, intersecting at D. Then, draw $A D$, and $A D$ will be the *resultant;* its *direction* is towards the point D, as shown by the arrow.

Measuring $A D$ we find that its length = 11.7 inches. Hence, $11.7 \times 10 = 117$ pounds. Ans.

CAUTION.—In solving problems by the graphical method, *use as large a scale as possible.* More accurate results are then obtained.

1916. The above example might also have been solved by the method called the **triangle of forces,** which is as follows:

In Fig. 630, suppose that the two forces acted separately, first from A to B, and then from B to D, in the direction of the arrows.

Draw $A D$; then $A D$ is the *resultant* of the forces $A B$ and $A C$, since $B D = A C$; but $A D$ is a side of the triangle $A B D$. It will also be noticed that the direction of $A D$ is *opposed* to that of $A B$ and $B D$; hence, to find the **resultant** of two forces acting upon a body at a common point, by the method of triangle of forces:

Rule.—*Draw the lines of action of the two forces as if each force acted separately, the lengths of the lines being proportional to the magnitude of the forces. Join the extremities of the two lines by a straight line, and it will*

be the resultant; its direction will be opposite to that of the two forces.

NOTE.—When we speak of the resultant being opposed in direction to the other forces around the polygon, we mean that, starting from the point where we began to draw the polygon, and tracing each line in succession, the pencil will have the same general direction around the polygon as if passing around a circle, from left to right, or from right to left, but that the closing line or resultant must have an *opposite direction*; that is, *the two arrow-heads must point towards the point of intersection of the resultant and the last side.*

1917. EXAMPLE.—Suppose the center of a headwheel is elevated 100 feet above the center of a hoisting-drum, as shown in Fig. 631. The rope from the headwheel to the hoisting-drum makes an angle of 30° with a vertical line, and the weight of the carriage and the load to be hoisted is 5 tons. (1) What force will there be on the shaft of the headwheel? (2) In what direction will the resultant force act, or what would be the direction in which the headwheel would be thrown if its shaft should break?

SOLUTION.—In Fig. 631, *A B C* represents the rope and its direction, with one end fastened to load *C*. The other end is passed over headwheel *B*, and wound around drum *A*. Now, as the rope is held in position by drum *A*, the tension at any point is equal to load *C*. Consequently, there is a force of 5 tons acting in the direction from *B* to *A*, as indicated by the arrow, and a like force acting in the direction from *B* to *C*, as indicated by the arrow. *B C* is assumed to be vertical. If we produce the lines *A B* and *C B* to *d*, *d* is the point of application; thus, we have the point of application, magnitude, and direction of the acting forces. Now, if we use a scale 1 inch = 1 ton, and lay off from *d*, the point of application, five inches or divisions on each component, as *d* to *1'*, *1'* to *2'*, *2'* to *3'*, *3'* to *4'*, *4'* to *5'*, and *d* to *1*, *1* to *2*, *2* to *3*, *3* to *4*, *4* to *5*, each inch or division represents one ton, and, consequently, the five inches

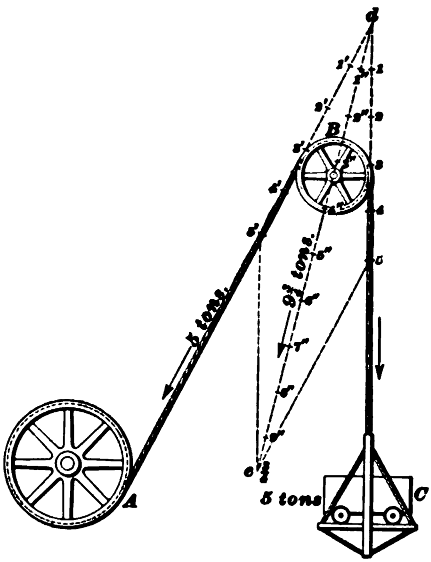


FIG. 631.

or divisions represent five tons, or the total force of each component. Then, by completing the parallelogram $d\,5'\,e\,5$, by drawing line $5'\,e$ parallel to $C\,B\,d$, and line $5\,e$ parallel to $A\,B\,d$, we have only to find how many times the resultant $d\,e$ contains the distance $d\,1$. If the resultant contains $d\,1$ seven times, then there is a force of 7 tons on the shaft B, acting in the direction $d\,e$, or if it contains $d\,1$ ten times, then there is a force of 10 tons on the shaft B, and so on. Consequently, there is one ton for each division we get on the line $d\,e$. Fig. 631 shows 9¾ such divisions; consequently, there are 9¾ tons on the shaft B, acting in the direction $d\,e$. The above discussion supposes the parts to be at rest.

1918. When three or more forces act upon a body at a given point, their *resultant* may be found by the following rule:

Rule.—*Find the resultant of any two forces; treat this resultant as a single force, and combine it with a third force to find a second resultant. Combine this second resultant with a fourth force, to find a third resultant, etc. After all the forces have been thus combined, the last resultant will be the resultant of all the forces, both in magnitude and direction.*

EXAMPLE.—Find the resultant of all the forces acting on the point O in Fig. 632, the length of the lines being proportional to the magnitude of the forces.

SOLUTION.—Draw $O\,E$ parallel and equal to $A\,O$, and $E\,F$ parallel and equal to $B\,O$; then, $O\,F$ is the resultant of these two forces, and its

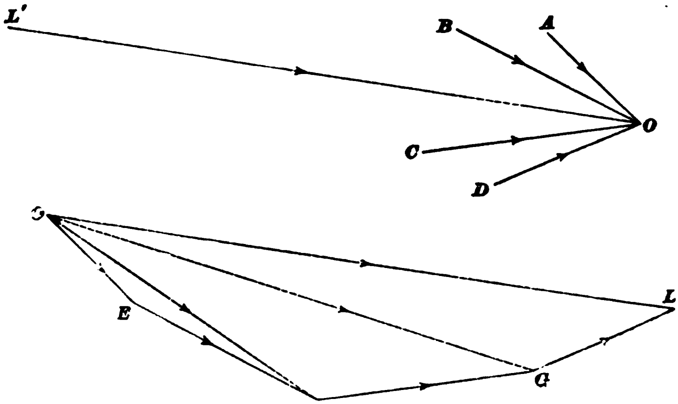


FIG. 632.

direction is from O to F, opposed to $O\,E$ and $E\,F$. Treat $O\,F$ as if $O\,E$ and $E\,F$ did not exist, and draw $F\,G$ parallel and equal to $C\,O$; $O\,G$ will be the resultant of $O\,F$ and $F\,G$; but $O\,F$ is the resultant of $O\,E$ and $E\,F$; hence, $O\,G$ is the resultant of $O\,E$, $E\,F$, and $F\,G$ and likewise of $A\,O$, $B\,O$, and $C\,O$. The line $F\,G$ parallel to $C\,O$ could not be drawn from the point O to the right of $O\,E$, for in that case it would be opposed in direction to $O\,F$; but $F\,G$ must have the same direction as $O\,F$, in order that the resultant may be opposed to both $O\,F$ and $F\,G$.

For the same reason, draw $G\,L$ parallel and equal to $D\,O$. Join O and L, and $O\,L$ will be the *resultant* of all the forces $A\,O$, $B\,O$, $C\,O$, and $D\,O$ (both in magnitude and direction), acting at the point O. If $L'O$ were drawn parallel and equal to $O\,L$, and having the same direction, it would represent the effect produced on the body by the combined action of the forces $A\,O$, $B\,O$, $C\,O$, and $D\,O$.

In Fig. 632, it will be noticed that $O\,E$, $E\,F$, $F\,G$, $G\,L$, and $L\,O$ are sides of a polygon $O\,E\,F\,G\,L$, in which $O\,L$, the resultant, is the closing side, and that its direction is opposed to that of all the other sides. This fact is made use of in what is called the **method of the polygon of forces.**

1919. To find the resultant of several forces acting upon a body at the same point:

Rule.—*Through a convenient point on the drawing, draw a line parallel to one of the forces, and having the same direction and magnitude. At the end of this line, draw another line parallel to a second force, and having the same direction and magnitude as this second force; at the end of the second line, draw a line parallel and equal in magnitude and direction to a third force. Thus continue until lines have been drawn parallel and equal in magnitude and direction to all of the forces.*

The straight line joining the free ends of the first and last lines will be the closing sides of the polygon; mark it opposite in direction to that of the other forces around the polygon, and it will be the resultant of all the forces.

EXAMPLE.—If five forces act upon a body at angles of 60°, 120°, 180°, 240°, and 270°, towards the same point, and their respective magnitudes

are 60, 40, 30, 25, and 20 pounds, find the magnitude and direction of their resultant by the method of polygon of forces.*

SOLUTION.—From a common point O, Fig. 633, draw the lines of action of the forces, making the given angles with a horizontal line through O, and mark them as acting towards O, by means of arrow-heads, as shown. Now, choose some convenient scale, such that the

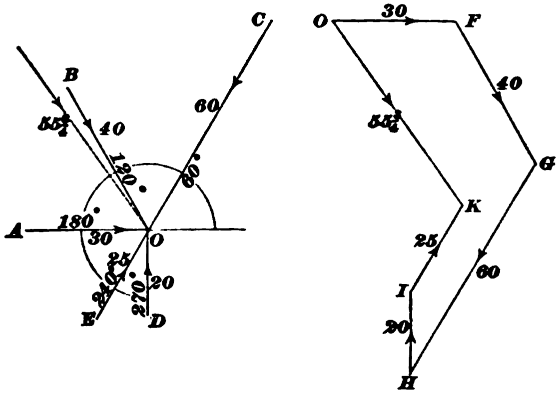


FIG. 633.

whole figure may be drawn in a space of the required size on the drawing. Choose any one of the forces, as $A O$, and draw $O F$ parallel to it, and equal in length to 30 pounds on the scale. It must also act in the same direction as $A O$. At F, draw $F G$ parallel to $B O$, and equal to 40 pounds. In a similar manner, draw $G H$, $H I$, and $I K$ parallel to $C O$, $D O$, and $E O$, and equal to 60, 20, and 25 pounds, respectively. Join O and K by $O K$, and $O K$ will be the resultant of the combined action of the five forces; its direction is opposite to that of the other forces around the polygon $O F G H I K$, and its magnitude = 55¾ pounds. Ans.

1920. If the resultant $O K$, in Fig. 633, were to act alone upon the body in the direction shown by the arrow-head with a force of 55¾ pounds, it would produce exactly the same effect upon a body as the combined action of the five forces.

If $O F$, $F G$, $G H$, $H I$, and $I K$ represent the distances and directions that the forces would move the body, if acting

* NOTE.—As stated in Trigonometry, all angles are measured from a horizontal line in a direction opposite to the movement of the hands of a watch (from around the circle to the left), from 1° or less, up to 360°.

separately, $O K$ is the direction and distance of movement of the body when all the forces act together.

From what has been said before, it is seen that any number of forces acting on the body at the same point, or having their lines of action pass through the same point, can be replaced by a *single force* (resultant) whose line of action shall pass through that point.

1921. Heretofore it has been assumed that the forces acted upon a single point on the *surface* of the body, but it

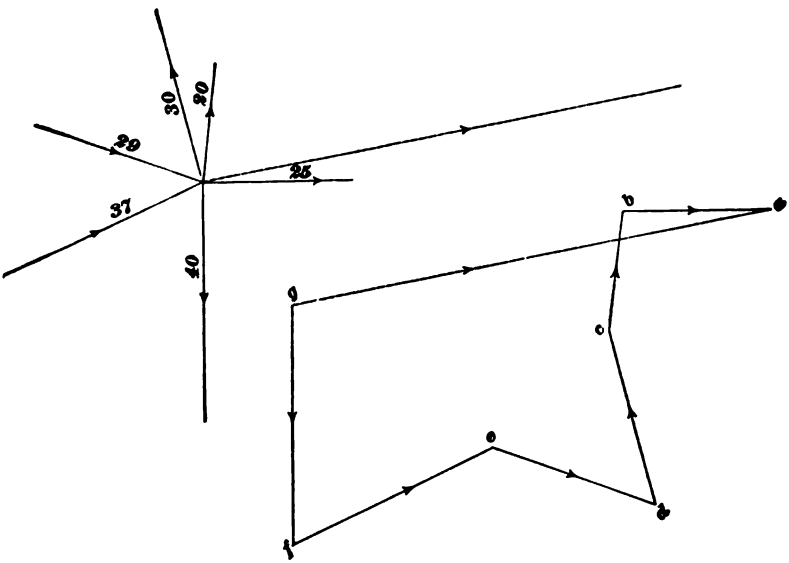


FIG. 634.

will make no difference where they act, so long as the lines of action of all the forces intersect at a *single point* either within or without the body, only so that the resultant can be drawn through the *point of intersection.* If two forces act upon a body in the same straight line and in the same direction, their *resultant* is the *sum of the two forces;* but if they act in opposite directions, their *resultant* is the *difference of the two forces*, and its direction is the same as that of the

greater force. If they are equal and opposite, the *resultant* is *zero*, or one force just balances the other.

EXAMPLE.—Find the resultant of the forces whose lines of action pass through a single point, as shown in Fig. 634.

SOLUTION.—Take any convenient point g, and draw a line gf, parallel to one of the forces, say the one marked 40, making it equal in length to 40 pounds on the scale, and indicate its direction by the arrow-head. Take some other force—the one marked 37 will be convenient; the line fe represents this force. From the point e, draw a line parallel to some other force, say the one marked 29, and make it equal in magnitude and direction to it. So continue with the other forces, taking care that the general direction around the polygon is not changed. The last force drawn in the figure is ab, representing the force marked 25. Join the points a and g; then, ag is the resultant of all the forces shown in the figure. Its direction is from g to a, opposed to the general direction of the others around the polygon. It does not matter in what order the different forces are taken, the resultant will be the same in magnitude and direction, if the work is done correctly.

THE RESOLUTION OF FORCES.

1922. Since two forces can be combined to form a single resultant force, we may also treat a single force as if it was the resultant of two forces, whose action upon a body will be the same as that of a single force. Thus, in Fig. 635, the force $O\ A$ may be resolved into two forces, $O\ B$ and $B\ A$, whose directions are opposed to $O\ A$.

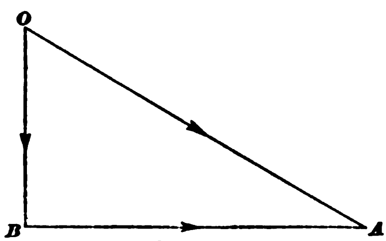


FIG. 635.

If the force $O\ A$ acts upon a body, moving or at rest upon a horizontal plane, and the resolved force $O\ B$ is vertical, and $B\ A$ horizontal, $O\ B$, measured to the same scale as $O\ A$, is the magnitude of that part of $O\ A$ which pushes the body *downwards*, while $B\ A$ is the magnitude of that part of the force $O\ A$ which is exerted in pushing the body in a *horizontal* direction. $O\ B$ and $B\ A$ are called the **components** of the force $O\ A$, and when these components

are vertical and horizontal, as in the present case, they are called the *vertical component* and the *horizontal component* of the force $O A$.

1923. It frequently happens that the position, magnitude, and direction of a certain force is known, and that it is desired to know the effect of the force in some direction other than that in which it acts. Thus, in Fig. 635, suppose that $O A$ represents, to some scale, the magnitude, direction, and line of action of a force acting upon a body at A, and that it is desired to know what effect $O A$ produces in the direction $B A$. Now, $B A$, instead of being horizontal, as in the cut, may have any direction. To find the value of the component of $O A$ which acts in the direction $B A$, we employ the following rule:

Rule.—*From one extremity of the line representing the given force, draw a line parallel to the direction in which it is desired that the component shall act; from the other extremity of the given force, draw a line perpendicular to the component first drawn, and intersecting it. The length of the component, measured from the point of intersection to the intersection of the component with the given force, will be the magnitude of the effect produced by the given force in the required direction.*

Thus, suppose $O A$, Fig. 635, represents a force acting upon a body resting upon a horizontal plane, and it is desired to know what *vertical pressure* $O A$ produces on the body. Here the desired direction is vertical; hence, from one extremity, as O, draw $O B$ parallel to the desired direction (vertical in this case), and, from the other extremity, draw $A B$ perpendicular to $O B$, and intersecting $O B$ at B. Then $O B$, when measured to the same scale as $O A$, will be the value of the vertical pressure produced by $O A$.

EXAMPLE.—If a body weighing 200 pounds rests upon an inclined plane whose angle of inclination to the horizontal is 18°, what force does it exert perpendicular to the plane, and what force does it exert parallel to the plane, tending to slide downwards?

SOLUTION.—Let $A B C$, Fig. 636, be the plane, the angle A being

equal to 18°, and let W be the weight. Draw a vertical line $FD =$ 200 pounds, to represent the magnitude of the weight. Through F, draw FE parallel to AB, and through D draw DE perpendicular to EF, the two lines intersecting at E. FD is now resolved into two components, one, FE, tending to pull the weight downwards, and the other, ED, acting as a perpendicular pressure on the plane.

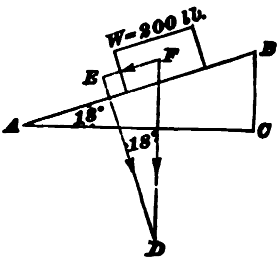


Fig. 636.

Since FD is perpendicular to AC and ED is perpendicular to AB, the angle $D =$ angle $A = 18°$.

Hence, $FE = 200 \times \sin 18° = 200 \times .30902 = 61.804$ pounds, and $ED = 200 \times \cos 18° = 200 \times .95106 = 190.212$ pounds.

Force parallel to the plane = 61.804 pounds.
Force perpendicular to the plane = 190.212 pounds. } Ans.

1924. Example.—In Fig. 637, a body W is shown resting on an inclined plane AB, whose dimensions are marked on the cut; the weight P acts to pull the body up the plane by means of the rope r and pulley p. It is required to find what the weight of P must be in order to start W up the plane. Suppose W weighs 120 pounds, and that friction is neglected. It is also required to find the perpendicular pressure which W exerts against the plane.

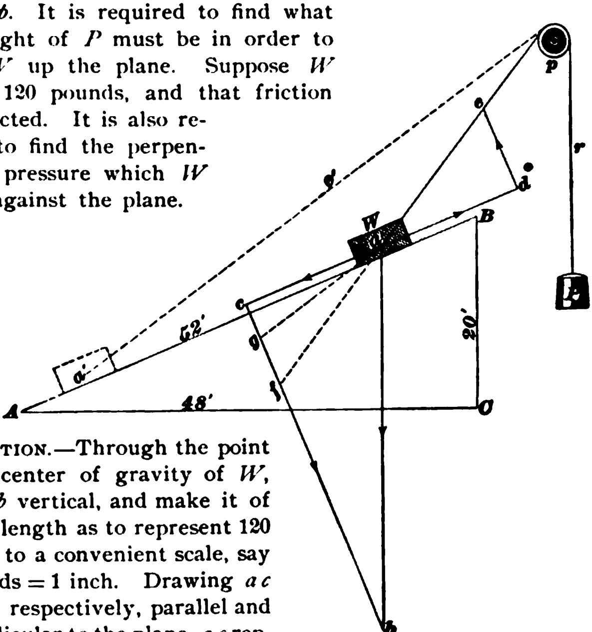


Fig. 637.

Solution.—Through the point a, the center of gravity of W, draw ab vertical, and make it of such a length as to represent 120 pounds to a convenient scale, say 60 pounds = 1 inch. Drawing ac and cb, respectively, parallel and perpendicular to the plane, ac represents the magnitude of the force

which must be exerted parallel to $A\,B$ in order to put the body in equilibrium, i. e., to balance the force which gravity exerts in pulling the body down the plane. If the rope r were parallel to $A\,B$, $a\,c$ would represent the weight of P; but, since r makes an angle with the plane, P will not be equal to $a\,c$. To find what the weight of P must be, draw $a\,d$ parallel to $a\,c$, but indicate it as acting in the opposite direction, or from a to d instead of from a to c. Now, treat $a\,d$ as though it were a *component* of the force acting in the rope; i. e., draw $d\,e$ perpendicular to $a\,d$, instead of perpendicular to $a\,e$. The reason for this is that if $d\,e$ were drawn perpendicular to $a\,e$, it could be resolved into components, one of which would be parallel to $a\,d$, a result which we wish to avoid; in other words, we want $d\,e$ perpendicular to the plane. The line $a\,e$, measured to the same scale as $a\,b$, will give the value of P. Measuring it, its length is .89 inch; hence, $P = .89 \times 60 = 53.4$ pounds. Ans.

To determine the perpendicular pressure against the plane, it will be noticed that $a\,b$ equals the pressure due to gravity. Since $c\,b$ and $d\,e$ are both perpendicular to $A\,B$, they are parallel, and since $d\,e$ acts in the opposite direction to $c\,b$, the actual pressure against the plane is given by the difference between $c\,b$ and $d\,e$. Making $c\,f$ equal to $d\,e$, $f\,b$ represents the perpendicular pressure against the plane when the force P ($= a\,e$) acts as shown. The length of $f\,b$ is 1.39 inches; hence, the perpendicular pressure is $1.39 \times 60 = 83.4$ pounds. Ans.

Since $c\,a$ and $a\,d$ are parallel and equal, and $c\,f$ and $d\,e$ are also parallel and equal, it follows that $a\,f$ and $a\,e$ must also be parallel and equal. Consequently, the force P might have been found by drawing $a\,f$ parallel to the direction in which the pull on the rope acts, and $b\,f$ perpendicular to the plane $A\,B$. Thus, suppose that the weight occupies the position shown by the dotted lines. Then, drawing $a\,g$ parallel to $a'\,e'$, $a\,g$ represents the weight of P, and $g\,b$ represents the perpendicular pressure of the body W against the plane. Measuring $a\,g$, its length is .79 inch; hence, $P = .79 \times 60 = 47.4$ pounds. Measuring $g\,b$, its length is 1.65 inches; hence, the perpendicular pressure $= 1.65 \times 60 = 99$ pounds.

1925. The results obtained by the graphic method can be obtained by trigonometry when the inclination of the plane and the angle the rope makes with the plane for any position of the weight W_1 are given.

Thus, $a\,c = a\,b \times \sin a\,b\,c = 120 \times \frac{20}{52} = 46.1538$ pounds.

Assuming the weight w to be in such a position that the rope r makes an angle of 30° 12′ with the inclined plane, and

since in the triangle $a\,d\,e$ the side $a\,d$ equals the side $c\,a$ in the triangle $a\,b\,c$, we have

$$a\,e = \frac{a\,d}{\cos e\,a\,d} = \frac{46.1538}{.86427} = 53.4 \text{ pounds. Ans.}$$

EXAMPLES FOR PRACTICE.

1. The current in a river which is $\frac{1}{2}$ mile wide has a velocity of $3\frac{3}{4}$ miles an hour. (*a*) What will be the actual distance that a boat will pass over in crossing the river, if the boat is rowed at the rate of 5 miles an hour? (*b*) How far down the river will the boat have been carried when it reaches the other side? (*c*) What time will the boat require to cross the river?

Ans. (*a*) $\frac{5}{8}$ mi.
(*b*) $\frac{3}{8}$ mi.
(*c*) 6 min.

2. What force acting parallel to a plane whose inclination is 30° will be required to support a trip of cars whose total weight is 25 tons?

Ans. $12\frac{1}{2}$ tons.

3. If a driver takes a side-hitch on a trip of cars standing on the turnout, with a mule that pulls with a force of say 400 pounds in a direction making an angle of 45° with the track, what force will tend to move the trip along the track? Ans. 282.85 lb.

4. Referring to Fig. 637, what would the angle $e\,a\,d$ become, if $P = 65.271$ pounds? Ans. 45°.

5. * The two ends of a rope 7 feet long are attached to the under side of a beam at points 5 feet apart; if a weight of one hundred pounds is firmly attached to the rope at a point 4 feet from one end, what will be the tension in each segment of the rope?

Ans. 60 lb. tension in long segment.
80 lb. tension in short segment.

6. What weight can be supported on a plane by a horizontal force of 1,521 pounds, if the ratio of the height to the base is $\frac{3}{4}$?

Ans. 2,028 lb.

7. What force is required (neglecting friction) to roll a barrel of oil weighing 300 pounds into a wagon 3 feet high by means of a plank 14 feet long resting against the wagon? Ans. $64\frac{2}{7}$ lb.

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* HINT.—To work this example by graphics, represent the weight by a vertical line drawn to scale; from one end of the line draw an indefinite line parallel to one of the segments of the rope, and from the other end of the line draw another indefinite line parallel to the other segment of the rope. These lines will intersect, and the distances from the point of intersection to the extremities of the vertical line will represent the tensions in the segments of the rope.

STRENGTH OF MATERIALS.

STRESSES AND STRAINS.

1926. When a force is applied to a body, it changes either its form or volume. A force, when considered with reference to the internal changes it tends to produce in any solid, is called a **stress.**

Thus, if a weight of 2 tons be held in suspension by a rod, the stress in the rod will be 2 tons. This stress is accompanied by a lengthening of the rod, which increases until the internal stress or resistance is in equilibrium with the external weight.

Stresses may be classified as follows:

Tensile, or pulling stress.

Compressive, or pushing stress.

Transverse, or bending stress.

Shearing, or cutting stress.

Torsional, or twisting stress.

1927. A **unit stress** is the amount of stress on a unit of area, and may be expressed either in pounds per square inch or in tons per square foot; or it is the load per square inch or square foot on any body.

Thus, if 10 tons are suspended by a wrought-iron bar which has an area of 5 square inches, the unit stress is 2 tons per square inch, because $\frac{10}{5} = 2$ tons.

1928. Strain is the deformation or change of shape of a body resulting from stress.

For example, if a rod 100 feet long is pulled in the direction of its length, and if it is lengthened 1 foot, it has a strain of $\frac{1}{100}$ of its length, or 1 per cent.

1929. Elasticity is the power which bodies have of returning to their original form after the external force on the body is withdrawn, providing the stress has not exceeded the elastic limit.

Consequently, we see from this that all material is

lengthened or shortened when subjected to either tensile or compressive stress, and the change of the length is directly proportional to the stress within the elastic limit.

For stresses within the elastic limits, materials are perfectly elastic, and return to their original length on removal of the stresses; but when their elastic limits are exceeded, the changes of their lengths are no longer regular, and a permanent **set** takes place; the destruction of the material has then begun.

1930. The **measure of elasticity** of any material is the change of length under stress within the elastic limit.

1931. The **elastic limit** is that unit stress under which the permanent set becomes visible.

The elasticity of wrought iron and that of steel are practically equal; that is, each material will change an equal amount of length under the same stress within the elastic limits.

The elastic limit of steel is higher than that of wrought iron; consequently, the former will lengthen or shorten more than the latter before its elasticity is injured.

TENSILE STRENGTH OF MATERIALS.

1932. The tensile strength of any material is the resistance offered by its fibers to being pulled apart.

The tensile strength of any material is proportional to the area of its cross-section.

Consequently, when it is required to find the safe tensile strength of any material, we have only to find the area at the minimum cross-section of the body, and multiply it by its strength per square inch, as given in Table 32 under the heading "Working Stress."

NOTE.—The minimum cross-section referred to in the above paragraph is that section of the material which is pierced with holes; such as bolt or rivet holes in iron, or knots in wood, if there are any.

1933. In Table 32 are given the average breaking and the working tensile stress of some materials.

The table shows that the tensile breaking strength

of cast iron is 16,000 pounds per square inch of cross-section, and that the working strength is from 1,500 to 3,500 pounds per square inch of cross-section.

TABLE 32.

Materials.	Breaking Stress in Pounds per Square Inch.	Working Stress in Pounds per Square Inch.
Timber................	10,000	600 to 1,200
Cast Iron..............	16,000	1,500 to 3,500
Wrought Iron..........	50,000	5,000 to 12,000
Steel..................	70,000	6,000 to 13,000

In machinery, such as steam-engines, where the parts are subjected to shocks, or are alternately compressed and extended, it is not safe to strain cast iron with more than 1,500 pounds per square inch of section, wrought iron with more than 5,000 pounds per square inch of section, or steel with more than 6,000 pounds per square inch of section.

But in structures in which the strains are constantly in one direction, as is the case with steam-boilers, wrought iron may be strained with from 6,000 to 8,000 pounds per square inch of section, or steel with from 8,000 to 10,000 pounds per square inch of section.

Consequently, strict attention must be given as to what working stress must be allowed for the materials of different structures.

NOTE.—For structures on which the load is applied suddenly, use the smaller working stresses given in the table, and for those on which the load is applied gradually, use the larger working stresses.

RULES AND FORMULAS FOR TENSILE STRENGTH.

1934. In the following formulas,

Let W = safe load in pounds;
A = area of minimum cross-section;
S = working stress in pounds per square inch, as given in Table 32.

Rule.—*The load in pounds on any bar subjected to a tensile strain is equal to the minimum sectional area of the bar, multiplied by the working stress in pounds per square inch, as given in Table 32.*

That is, $$W = A\,S. \qquad \textbf{(118.)}$$

EXAMPLE.—A bar of good wrought iron which is 3 inches square is to be subjected to a steady tensile stress; what is the maximum load that it should carry?

SOLUTION.—From what has been said above in regard to the materials and to the nature of the load, it will be safe in this case to use a working stress of 12,000 pounds per square inch.

Applying formula **118,** we have

$$W = 3 \times 3 \times 12{,}000 = 108{,}000 \text{ pounds.} \quad \text{Ans.}$$

1935. Rule.—*The minimum sectional area of any bar subjected to a tensile stress is equal to the load in pounds, divided by the working stress in pounds per square inch, as given in Table 32.*

That is, $$A = \frac{W}{S}. \qquad \textbf{(119.)}$$

EXAMPLE.—What should be the area of a wrought-iron bar to carry a steady load of 66,000 pounds, if it is to resist a tensile stress of 12,000 pounds per square inch?

SOLUTION.—Applying formula **119,**

$$A = \frac{66{,}000}{12{,}000} = 5.5 \text{ sq. in.} \quad \text{Ans.}$$

1936. Rule.—*The working stress in pounds per square inch is equal to the load in pounds divided by the minimum sectional area of the bar.*

That is, $$S = \frac{W}{A}. \qquad \textbf{(120.)}$$

EXAMPLE.—A bar of wrought iron 3 inches square, subjected to tensile stress, carries a load of 86,400 pounds; what is the stress per square inch?

SOLUTION.—Applying formula **120,**

$$S = \frac{86{,}400}{3 \times 3} = 9{,}600 \text{ lb. per sq. in.} \quad \text{Ans.}$$

STRENGTH OF CHAINS.

1937. Chains made of the same size iron vary in strength, owing to the different kinds of links from which they are made.

It is a good practice to anneal old chains which have become brittle by overstraining. This renders them less liable to snap from sudden jerks. It reduces their tensile strength, but increases their toughness and ductility, which are sometimes more important qualities.

1938. In the following formulas,

Let W = safe load in pounds sustained by chain;
D = diameter in inches of the iron from which the links are made.

Rule.—*The safe load in pounds of a stud-link wrought-iron chain is equal to 18,000, multiplied by the square of the diameter of the iron from which the links are made.*

That is, $W = 18{,}000\, D^2$. **(121.)**

Example.—What is the maximum load that should be carried by a stud-link wrought-iron chain, if its links are made from $\frac{3}{4}$-inch round iron?

Solution.—Applying formula **121**, we have

$$W = 18{,}000 \times \tfrac{3}{4} \times \tfrac{3}{4} = 10{,}125 \text{ pounds. Ans.}$$

1939. **Rule.**—*The safe load in pounds of a close-link wrought-iron chain is equal to 12,000 multiplied by the square of the diameter of the iron from which the links are made.*

That is, $W = 12{,}000\, D^2$. **(122.)**

Example.—What is the maximum load that should be carried by a close-link wrought-iron chain, if its links are made from $\frac{3}{4}$-inch round iron?

Solution.—Applying formula **122**, we have

$$W = 12{,}000 \times \tfrac{3}{4} \times \tfrac{3}{4} = 6{,}750 \text{ pounds. Ans.}$$

STRENGTH OF HEMP ROPES.

1940. The strength of hemp ropes does not depend so much upon the quality of the material and the cross-section of the rope as upon the method of manufacture and the amount of twisting.

The ropes in common use are three-strand shroud-laid rope, and hawser or cable-laid rope.

The strongest ropes are three-strand shroud-laid made without tar. Ropes made with tar are less flexible, and are reduced in strength about 25 per cent., but have better wearing qualities.

1941. In the following formulas,

Let W = maximum working load in pounds;

C = circumference of rope in inches.

Rule.—*The maximum working load in pounds that should be allowed on any hemp rope is equal to the square of the circumference of the rope multiplied by 100.*

That is, $W = 100\,C^2$. **(123.)**

EXAMPLE.—What is the maximum load in pounds that should be carried by a hemp rope which has a circumference of 8 inches?

SOLUTION.—Substituting the value of C in formula **123**,

$W = 100 \times 8^2 = 6{,}400$ lb. Ans.

1942. Rule.—*The circumference of any hemp rope is equal to the square root of the maximum working load in pounds which it is capable of carrying, multiplied by .1.*

That is, $C = .1\sqrt{W}$. **(124.)**

EXAMPLE.—A maximum working load of 1,000 pounds is to be carried by a hemp rope; what should be the circumference of the rope?

SOLUTION.—Applying formula **124**,

$C = .1\sqrt{1{,}000} = 3.16$ inches. Ans.

When measuring ropes, the circumference is sought instead of the diameter, because the ropes are not round and the circumference is not 3.1416 times the diameter. For three strands, the circumference is about 2.86 d; for seven strands, 3 d.

STRENGTH OF WIRE ROPES.

1943. Wire rope is made of iron and steel wire. It is stronger than hemp rope, and, to carry the same load, is of smaller diameter.

In substituting steel for iron rope, the object in view

should be to gain an increase of wear from the rope, rather than to reduce the size.

A steel rope to be serviceable should be of the best obtainable quality, because ropes made from low grades of steel are inferior to good iron ropes.

1944. In the following formulas,

Let $W =$ maximum working load in pounds;
$C =$ circumference of rope in inches.

Rule.—*The maximum working load in pounds that should be allowed on any wire rope is equal to the square of the circumference of the rope in inches, multiplied by 600.*

That is, $W = 600\ C^2$. **(125.)**

Example.—What is the maximum load in pounds that should be carried by an iron wire rope whose circumference is $4\frac{1}{2}$ inches?

Solution.—Applying formula **125**,

$$W = 600 \times 4.5^2 = 12{,}150 \text{ lb. Ans.}$$

1945. Rule.—*The circumference of any iron wire rope in inches is equal to the square root of the maximum working load in pounds multiplied by .0408.*

That is, $C = .0408\sqrt{W}$. **(126.)**

Example.—A maximum working load of 12,150 pounds is to be carried by an iron wire rope; what should be the minimum circumference of the rope?

Solution.—Applying formula **126**,

$$C = .0408\sqrt{12{,}150} = 4\tfrac{1}{2} \text{ inches. Ans.}$$

1946. Rule.—*The above rules and formulas are also applicable when computing the safe strength of steel wire rope by substituting the constant 1,000 for the constant 600, and .0316 for .0408.*

Example.—What is the maximum load in pounds that should be carried by a steel wire rope, the circumference of which is $4\frac{1}{2}$ inches?

Solution.—Applying formula **125** as modified by the rule,

$$W = 1{,}000 \times 4.5^2 = 20{,}250 \text{ lb. Ans.}$$

Example.—A maximum working load of 10,485 pounds is to be

carried by a steel wire rope; what should be the minimum circumference of the rope?

SOLUTION.—Applying formula **126** as modified by the rule,

$$C = .0316\sqrt{10,485} = 3.24 \text{ inches. Ans.}$$

EXAMPLES FOR PRACTICE.

1. What should be the diameter of a steel piston-rod of a steam-engine to resist tension, if the piston is 19 inches in diameter and the pressure is 85 pounds per sq. in.? Ans. 2¼ in., nearly.

2. What safe load will a cast-iron bar of rectangular cross-section 7½ inches by 3½ inches support if subjected to shocks? The bar is in tension. Ans. 39,375 lb.

3. What is the stress per square inch on a piece of timber 8 inches square, which is subjected to a steady pull of 60,000 pounds? Ans. 937.5 lb. per sq. in.

4. What should be the safe load for a close-link wrought-iron chain whose links are made from ⅞-inch iron? Ans. 9,187.5 lb.

5. What safe load may a hemp rope carry whose circumference is 4 inches? Ans. 1,600 lb.

6. What should be the allowable working load for a steel wire rope whose circumference is 3¾ inches? Ans. 14,062.5 lb.

7. What should be the circumference of an iron wire rope to support a load of 20,000 pounds? Ans. 5¾ in., nearly.

CRUSHING STRENGTH OF MATERIALS.

1947. The crushing strength of any material is the resistance offered by its fibers to being pushed together.

If a bar is long compared with its cross dimensions, any slight disturbance from uniformity will cause it to bend sideways under the compressive force, and we have, then, not only compression, but compression compounded with bending.

To obtain only compression, the length of a rod should not be more than five times greater than its least diameter, or its least thickness when it is a rectangular rod.

Experimental tests on pillars have shown that their strengths are approximately inversely proportional to the squares of their lengths. That is, if there are two pillars of the same material, having the same cross-section, but

one is twice as long as the other, the long one will sustain only about one-quarter the load of the short one.

1948. Attention should be given to the ends of pillars, as their shape has great influence upon their strength. In Fig. 638 are shown three pillars with different shaped ends.

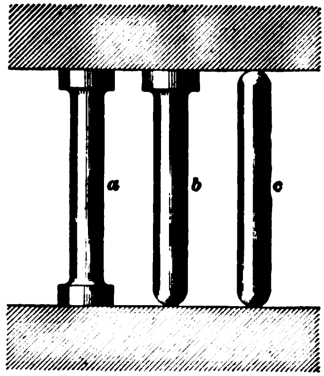


FIG. 638.

It has been proved by the aid of higher mathematics that, theoretically, a pillar having flat or fixed ends, as shown at *a*, is four times as strong as one that has round or movable ends, as shown at *c*, and one and seven-ninths times as strong as one having one flat and one round end, as shown at *b*; *b* is thus two and one-fourth times as strong as *c*. It has also been found that if three pillars, *a*, *b*, *c*, which have the same cross-section, are to carry the same load and be of equal strength, their lengths must be as the numbers 2, 1½, and 1, respectively.

In practice, however, the ends of the pillars *b* and *c* are not generally made as shown by the figure, but have holes at their ends into which pins are fitted which are fastened to some other piece; as, for example, a connecting-rod of an engine. In such cases, it has been found that *a* is two times as strong as *c*, and that *b* is one and one-half times as strong as *c*. That is, in actual practice, a column fixed as at *c* is really one-half as strong as one fixed as at *a*, instead of being only one-quarter as strong, as given above.

Green or wet timber has only one-half the strength of dry and seasoned timber; consequently, its crushing strength is only one-half of that given in the table below.

1949. In Table 33 is given the mean crushing strength of some short specimens of materials in tons (of 2,000 pounds) per square inch.

TABLE 33.

Materials.	Crushing Strength in Tons per Square Inch.
Cast Iron	40
Wrought Iron	18
Mild Steel	26
Cast Copper	5
Cast Brass	4.5
Timber (Dry)	3.5
Brick	1
Stone	3

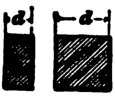
STRENGTH OF PILLARS.

1950. The following formula is applicable to pillars which are commonly used in practice, the lengths of which are about from 10 to 40 times their least diameter, or, if rectangular, their least thickness as indicated by d:

Let C = crushing strength in tons per square inch of a short specimen of the material as given in Table 33;
S = sectional area in square inches;
L = length in inches;
d = least thickness of rectangular pillar, or diameter of round pillar in inches;
W = breaking load in tons;
A = the area of the two flanges;
B = the area of the web;
a = a constant for the particular form of cross-section and material of which the pillar is made; its value is given in Tables 34 to 36 for such cross-sections as are given in the first column of those tables, and for such material as is mentioned at the top of the tables.

TABLE 34.

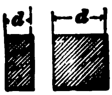
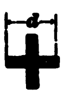
WROUGHT-IRON PILLARS.

Cross-section of Pillar.	When Both Ends of the Pillar are Flat or Fixed.	When One End of the Pillar is Flat or Fixed, and the Other Round or Movable.	When Both Ends of the Pillar are Round or Movable.
 Round.	2,250	1,500	1,125
 Square or Rectangle.	3,000	2,000	1,500
 Thin Square Tube.	6,000	4,000	3,000
 Thin Round Tube.	4,500	3,000	2,250
 Angle with Equal Sides.	1,500	1,000	750
 Cross with Equal Arms.	1,500	1,000	750
 I Beam.	$3,000 \times \frac{A}{A+B}$	$2,000 \times \frac{A}{A+B}$	$1,500 \times \frac{A}{A+B}$

1951. Rule.—*The breaking load of a pillar in tons is equal to the crushing strength of a short specimen of the material as given in Table 33, multiplied by the sectional area of the pillar in square inches, and the product divided by*

TABLE 35.

CAST-IRON PILLARS.

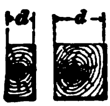
Cross-section of Pillar.	When Both Ends of the Pillar are Flat or Fixed.	When One End of the Pillar is Flat or Fixed, and the Other Round or Movable.	When Both Ends of the Pillar are Round or Movable.
 Round.	281.25	187.5	140.625
 Square or Rectangle.	375.00	250.0	187.500
 Thin Square Tube.	750.00	500.0	375.000
 Thin Round Tube.	562.50	375.0	281.250
 Angle with Equal Sides.	187.50	125.0	93.750
 Cross with Equal Arms.	187.50	125.0	93.750
 I Beam.	$375 \times \frac{A}{A+B}$	$250 \times \frac{A}{A+B}$	$125 \times \frac{A}{A+B}$

the result obtained by dividing the square of the length of the pillar in inches by the square of the diameter, or least thickness if rectangular, multiplied by the value of a, plus 1.

That is,
$$W = \frac{C\,S}{\frac{L^2}{a\,d^2} + 1}. \qquad \textbf{(127.)}$$

TABLE 36.

WOODEN PILLARS.

Cross-section of Pillar.	When Both Ends of the Pillar are Flat or Fixed.	When One End of the Pillar is Flat or Fixed, and the Other Round or Movable.	When Both Ends of the Pillar are Round or Movable.
 Round.	187.5	125.00	93.75
 Square or Rectangle.	250.0	166.66	125.00
 Hollow Square Made of Boards.	500.0	333.33	250.00

The result obtained by the formula must be divided by 6 to get the safe working load.

NOTE.—If the length of the pillar is given in feet, be sure to reduce it to inches before substituting in the formula.

EXAMPLE.—A wooden pillar 6 inches square and 144 inches long is fixed at both ends; what load will it sustain with safety?

SOLUTION.—Using formula **127**, we have

$$W = \frac{3.5 \times 6 \times 6}{\dfrac{144 \times 144}{250 \times 6 \times 6} + 1} = 38.14 \text{ tons, nearly.}$$

Which, divided by 6, gives $\frac{38.14}{6} = 6.357$ tons, or the load it is capable of sustaining with safety. Ans.

EXAMPLE.—A wrought-iron pillar 4 inches in diameter and 60 inches long is fixed at one end and movable at the other; what load will it sustain with safety?

SOLUTION.—Using formula **127**,

$$W = \frac{18 \times 4 \times 4 \times .7854}{\dfrac{60 \times 60}{1{,}500 \times 4 \times 4} + 1} = 196.69 \text{ tons.}$$

Which, divided by 6, gives $\frac{196.69}{6} = 32.78$ tons, nearly, or the load it is capable of sustaining with safety. Ans.

EXAMPLE.—A cast-iron pillar is 20 feet long and its cross-section is a cross with equal arms which are 1 inch thick and 10 inches long. (See dimension *d*, Table 35.) The two ends of the pillar are movable. What load will the column safely sustain?

SOLUTION.—Area of cross-section is equal to $(10 \times 1) + 2(4.5 \times 1) = 19$ square inches; 20 feet are equal to 240 inches.

Now, applying formula **127**,

$$W = \frac{40 \times 19}{\frac{240 \times 240}{93.75 \times 10 \times 10} + 1} = 106.38 \text{ tons.}$$

Which, divided by 6, gives $\frac{106.38}{6} = 17.73$ tons, the load it is capable of sustaining with safety. Ans.

When using formula **127**, first obtain the value of C from Table 33. Next, calculate the area of the cross-section of the pillar. Then, find the value of a from one of the tables. Finally, be sure that the length of the pillar has been reduced to inches before substituting in the formula.

EXAMPLES FOR PRACTICE.

1. What load may be safely carried by a hollow cylindrical cast-iron pillar 20 ft. long, inside diameter 8", and outside diameter 10"? Both ends of the pillar are fixed. Ans. 93.13 tons.

2. A rectangular wooden column is 14 ft. long, and has one end rounded; if the cross-section is 12" × 8", what load will be required to break it? Ans. 92.15 tons.

3. A solid wrought-iron column, which has both ends movable, is 3" in diameter and 8 ft. long; what load will it safely support? Ans. 11.1 tons.

TRANSVERSE STRENGTH OF MATERIALS.

1952. The transverse strength of any material is the resistance offered by its fibers to being broken by bending. As, for example, when a beam, bar, rod, etc., which is supported at its ends, is broken by a force applied between its supports.

The transverse strength of any beam, bar, rod, etc., is proportional to the product of the square of its depth multiplied by its width; consequently, it is more economical to increase the depth than the width.

TABLE 37.

CONSTANTS FOR TRANSVERSE STRENGTH.

Materials.	Safe Transverse Strength in Pounds.	Materials.	Safe Transverse Strength in Pounds.
METALS.		WOODS.	
Cast Iron	100	Birch	35
Wrought Iron	150	Elm	25
Structural Steel	160	Ash	45
Copper	50	Beech	30
Brass	55	Hickory	50
		Maple	60
		Oak (American)	45
		Pine (Pitch)	40
		Pine (White)	30

1953. A **cantilever** is a beam, bar, rod, etc., fixed at one end and subjected to a transverse stress, as shown in Fig. 639. It has a tendency to overthrow the wall or structure to which it is attached.

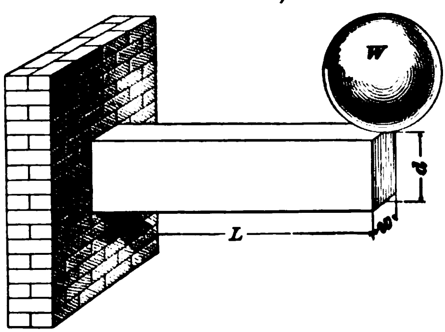


FIG. 639.

The strength of a cantilever varies inversely as the distance of the load from the section acted upon; and the stress upon any section varies directly as the distance of the load from that section

The strength of a beam, bar, rod, etc., which has both its ends supported, but not fixed, and which is loaded in the middle between its supports, is four times greater than when it is fixed at one end only.

A cantilever uniformly loaded will sustain twice as great a load as one on which the load is applied at one end; and a beam resting on two supports uniformly loaded will sustain twice as great a load as one on which the load is applied in the middle, between its supports.

In Table 37 is given the safe transverse strength of bars of different kinds of material, 1 inch square and 1 foot long, with the load suspended from one end.

RULES AND FORMULAS FOR THE TRANSVERSE STRENGTH OF BEAMS.

1954. In the following formulas,

Let d = the depth of beam in inches;
d_1 = diameter of cylindrical beam in inches;
w = the width of the beam in inches;
L = the length of the beam in feet between its supports;
S = the safe transverse strength as given in the above table;
W = the safe load in pounds.

For a rectangular or square cantilever to which the load is applied at one end, as shown in Fig. 639:

Rule.—*To find the maximum safe load in pounds that should be allowed at the end of any rectangular or square cantilever, multiply the square of the depth in inches by the width in inches and by the safe transverse strength of the material as given in Table 37; divide this product by the length in feet.*

That is, $$W = \frac{d^2 w S}{L}. \qquad \textbf{(128.)}$$

Example.—What is the maximum safe load that can be placed at one end of a cast-iron bar which projects 4 feet, the depth being 6 inches and the width 8 inches?

SOLUTION.—Applying formula **128**, we have

$$W = \frac{6 \times 6 \times 3 \times 100}{4} = 2{,}700 \text{ pounds. Ans.}$$

1955. For a cylindrical cantilever to which the load is applied at one end, as shown in Fig. 640:

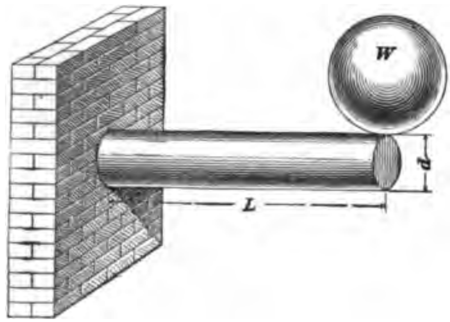


FIG. 640.

Rule.—*To find the maximum safe load in pounds that should be allowed at the end of any cylindrical cantilever, multiply the cube of its diameter in inches by .6 of the safe transverse strength of the material as given in Table 37, and divide the product by the length in feet.*

That is, $$W = \frac{d_1^3 \times .6\,S}{L}. \qquad \textbf{(129.)}$$

EXAMPLE.—What is the maximum load that can be placed with safety at one end of a cast-iron bar 4 inches in diameter that projects 3 feet?

SOLUTION.—Applying formula **129**, we have

$$W = \frac{4 \times 4 \times 4 \times .6 \times 100}{3} = 1{,}280 \text{ pounds. Ans.}$$

1956. When the load is uniformly distributed on a cantilever of any cross-section, as shown in Fig. 641, it will sustain a load twice as great as when the load is applied at one end. For example, if the cantilevers in the two examples above were to carry a uniformly distributed load, they would sustain 2,700 × 2 = 5,400 pounds and 1,280 × 2 = 2,560 pounds, respectively.

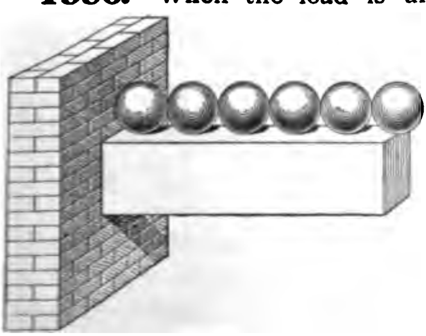


FIG. 641.

1957. For a rectangular or square beam the ends of which merely rest upon supports, and loaded in the middle, as shown in Fig. 642:

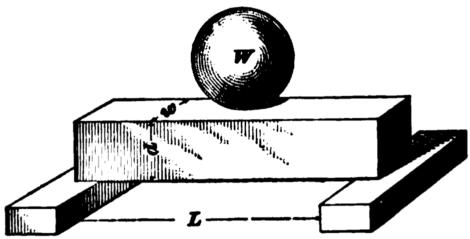


FIG. 642.

Rule.—*To find the maximum safe load in pounds that any rectangular or square beam is capable of sustaining at the middle when its ends merely rest upon supports, multiply four times the square of its depth in inches, by its width in inches, and by the safe strength of the material as given in Table 37; divide this product by the distance between its supports in feet;*

or, $$W = \frac{4\,d^2\,w\,S}{L}. \qquad \textbf{(130.)}$$

EXAMPLE.—What maximum safe load is a bar of cast iron capable of sustaining in the middle between its supports on which its ends merely rest, if its depth is 6 inches, its width 3 inches, and the distance between the supports is 4 feet?

SOLUTION.—Applying formula **130**,

$$W = \frac{4 \times 6^2 \times 3 \times 100}{4} = 10{,}800 \text{ lb.} \quad \text{Ans.}$$

1958. For a cylindrical beam supported at its ends and loaded in the middle, as shown in Fig. 643:

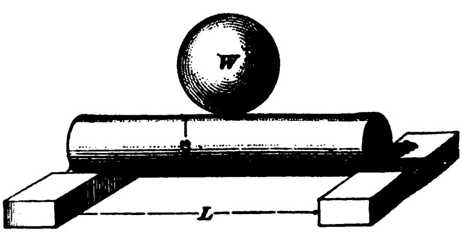


FIG. 643.

Rule.—*To find the maximum safe load in pounds that any cylindrical beam is capable of sustaining at the middle when its ends merely rest upon supports, multiply four times the cube of its diameter by .6 of the safe strength of the material as given in Table 37; divide this product by the distance between its supports in feet;*

or, $$W = \frac{4\,d_1^3 \times .6\,S}{L}. \qquad \textbf{(131.)}$$

EXAMPLE.—What maximum safe load is a bar of cast iron capable of sustaining in the middle between its supports, on which its ends merely rest, if it is 4 inches in diameter, and if the distance between its supports is 3 feet?

SOLUTION.—Applying formula **131**,

$$W = \frac{4 \times 4^3 \times .6 \times 100}{3} = 5{,}120 \text{ lb. Ans.}$$

1959. When the load is uniformly distributed on a beam of any cross-section, as shown in Fig. 644, it will sustain a load twice as great as when the load is applied in the middle between the supports.

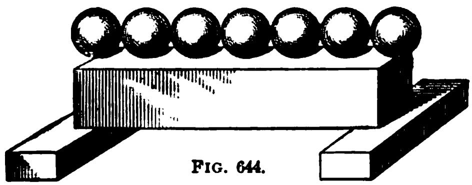


FIG. 644.

For example, if the beams in the last two examples were to carry a uniformly distributed load, they would sustain 10,800 × 2 = 21,600 pounds, and 5,120 × 2 = 10,240 pounds, respectively.

SHEARING OR CUTTING STRENGTH OF MATERIALS.

1960. The shearing strength of any material is the resistance offered by its fibers to being cut in two.

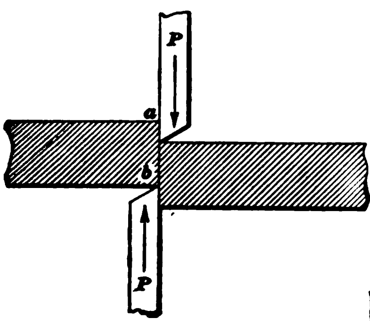


FIG. 645.

Thus the pressure of the cutting edges of an ordinary shearing machine, Fig. 645, causes a shearing stress in the plane *a b*. The unit shearing force may be found by dividing the force *P* by the area of the plane *a b*.

1961. Fig. 646 shows a piece in double shear; here the central piece *c d*

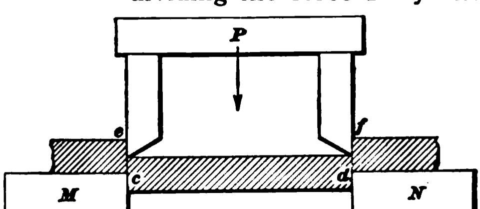


FIG. 646.

is forced out while the ends remain on their supports M and N.

The shearing strength of any body is directly proportional to its area.

1962. In Table 38 are given the greatest and the safe shearing strengths per square inch of different kinds of materials:

TABLE 38.

Materials.	Greatest Shearing Stress in Pounds per Square Inch.	Safe Shearing Stress in Pounds per Square Inch.
Cast Iron.	18,000	1,500 to 3,000
Wrought Iron.	40,000	4,000 to 10,000
Steel	60,000	5,000 to 12,000

1963. In the following formula,

Let a = area of cross-section in inches;
S = safe shearing stress, as given in Table 38;
W = safe load in pounds.

Rule.—*The safe load that any body which is subjected to a shearing stress is capable of sustaining is equal to the area of its cross-section in inches, multiplied by its safe shearing stress, as given in Table 38.*

That is, $W = a\,S$. **(132.)**

EXAMPLE.—If the beam in Fig. 646 is made of wrought iron 4 inches in depth and 2 inches in width, what steady shearing stress is it capable of sustaining with safety?

SOLUTION.—Applying formula **132**, $W = 4 \times 2 \times 10{,}000 = 80{,}000$ lb. This result must be multiplied by 2, since the beam is sheared in two places, along the lines $e\,c$ and $f\,d$. Hence, the stress which the beam will safely sustain is $80{,}000 \times 2 = 160{,}000$ lb. Ans.

EXAMPLE.—What force is required to punch a hole $\frac{3}{4}''$ in diameter through a steel plate $\frac{1}{2}''$ thick?

SOLUTION.—It is evident that punching is but shearing in a circle instead of a straight line. The area punched (sheared) is equal to the

thickness of the plate multiplied by the circumference of a circle having the same diameter as the punched hole. For, if the plate were cut through one of the diameters of the punched hole and the two semicircles were straightened out, the punched surface would be a rectangle, which would have a length equal to the circumference of a circle whose diameter was equal to that of the hole, and a breadth equal to the thickness of the plate. In this case, the area $= \frac{5}{8} \times 3.1416 \times \frac{1}{2} = .98175$ sq. in. Table 38 gives the ultimate shearing strength of steel as 60,000 lb. per sq. in. Hence, the total force required is $.98175 \times 60{,}000 = 58{,}905$ lb. Ans.

EXAMPLES FOR PRACTICE.

1. What is the greatest load that can be safely carried by a steel rectangular cantilever at its extreme end, if the bar is 2" wide, 3" deep, and 2 ft. 6" long? Ans. 1,152 lb.

2. What is the greatest uniform load that can be safely carried by a white pine girder 6" wide, 8" deep, 16 ft. long, and supported at its ends? Ans. 5,760 lb.

3. A cast-iron bar $1\frac{3}{8}$" in diameter and 5 ft. 3" long is supported at its ends; what load will it safely sustain in the middle? Ans. 245 lb.

4. What force is required to punch a $1\frac{1}{4}$" hole through a wrought-iron plate $\frac{7}{16}$" thick? Ans. 68,723 lb.

5. What force is required to cut off the end of a cast-iron bar whose diameter is $2\frac{1}{2}$"? Ans. 88,357 lb.

LINE SHAFTING.

1964. A line of shafting is one continuous run, or length, composed of lengths of shafts joined together by couplings.

The **main line** of shafting is that which receives the power from the engine or motor, and distributes it to the other lines of shafting, or to the various machines to be driven.

Line shafting is supported by hangers, which are brackets provided with bearings bolted either to the walls, posts, ceilings, or floors of the building. Short lengths of shafting called **countershafts** are provided to effect changes of speed, and to enable the machinery to be stopped or started.

Shafting is usually made cylindrically true, either by a special rolling process known as **cold-rolled shafting**, or

else it is turned up in a machine called a lathe. In the latter case, it is called **bright shafting.** What is known as **black shafting** is simply bar iron rolled by the ordinary process, and turned where it receives the couplings, pulleys, bearings, etc.

Bright-turned shafting varies in diameter by $\frac{1}{4}$ of an inch to about $3\frac{1}{2}$ inches in diameter; above this diameter the shafting varies by $\frac{1}{2}$ inch. The actual diameter of a bright shaft is $\frac{1}{16}$ of an inch less than the actual commercial diameter, it being designated from the diameter of the ordinary round bar-iron from which it is turned. Thus, a length of what is called 3-inch bright shafting is only $2\frac{15}{16}$ inches in diameter.

Cold-rolled shafting is designated by its actual commercial diameter; thus, a length of what is called 3-inch shafting is 3 inches in diameter.

1965. In Table 39 is given the maximum distance between the bearings of some continuous shafts which are used for the transmission of power.

TABLE 39.

Diameter of Shaft in Inches.	Distance Between Bearings in Feet.	
	Wrought-Iron Shaft.	Steel Shaft.
2	11	11.5
3	13	13.75
4	15	15.75
5	17	18.25
6	19	20.00
7	21	22.25
8	23	24.00
9	25	26.00

The necessary diameters of the various lengths of shafts composing a line of shafting should be proportional to the

quantity of power delivered by each respective length. In this connection, the positions of the various pulleys depend upon the distance between the pulley and the bearing and upon the amount of power given off by the pulleys. Suppose, for example, that a piece of shafting delivers a certain amount of power; then, it is obvious that the shaft will deflect or bend less if the pulley transmitting that power be placed close to a hanger or bearing than if it be placed midway between the two hangers or bearings.

NOTE.—It is impossible to give any rule for the proper distance of bearings which could be used universally, as in some cases the requirements demand that the bearings be nearer together than in others.

1966. To compute the horsepower that can be transmitted by a shaft of any given diameter:

Let D = diameter of shaft;
R = revolutions per minute;
H = horsepower transmitted;
C = constant taken from the following table:

TABLE 40.
CONSTANTS FOR LINE SHAFTING.

Material of Shaft.	No Pulleys Between Bearings.	Pulleys Between Bearings.
Steel or Cold-Rolled Iron ..	65	85
Wrought Iron	70	95
Cast Iron	90	120

Rule.—*The horsepower that a shaft will transmit is equal to the product of the cube of the diameter and the number of revolutions, divided by the value of C for the given material.*

That is, $$H = \frac{D^3 R}{C}. \qquad \textbf{(133.)}$$

EXAMPLE.—What horsepower will a 3-inch wrought-iron shaft transmit, which makes 100 revolutions per minute, and has pulleys between bearings?

SOLUTION.—Applying formula **133,** we have

$$H = \frac{3 \times 3 \times 3 \times 100}{95} = 28.42 \text{ horsepower. Ans.}$$

1967. To compute the number of revolutions a shaft must make to transmit a given horsepower:

Rule.—*The number of revolutions necessary for a given horsepower is equal to the product of the value of the constant C for the given material and the number of horsepower, divided by the cube of the diameter.*

That is, $$R = \frac{CH}{D^3}. \qquad \textbf{(134.)}$$

Example.—How many revolutions must a 2-inch steel shaft make per minute to transmit 16 horsepower? There are no pulleys between bearings.

Solution.—Applying formula **134,** we have $\frac{65 \times 16}{2 \times 2 \times 2} = 130$ revolutions. Ans.

1968. To compute the diameter of a shaft that will transmit a given horsepower, the number of revolutions the shaft makes per minute being given:

Rule.—*The diameter of a shaft equals the cube root of the quotient obtained by dividing the product of the value of the constant C for the given material and the number of horsepower by the number of revolutions.*

That is, $$D = \sqrt[3]{\frac{CH}{R}}. \qquad \textbf{(135.)}$$

Example.—What must be the diameter of a cast-iron shaft to transmit 22.5 horsepower? The shaft makes 100 revolutions per minute, and there are pulleys between bearings.

Solution.—Applying formula **135,** we have

$$D = \sqrt[3]{\frac{120 \times 22.5}{100}} = 3 \text{ in. Ans.}$$

1969. As the speed of shafting is used as a multiplier in the calculations of the horsepower of shafts, a shaft having a given diameter will transmit more power in proportion as its speed is increased. Thus, a shaft which is capable of transmitting 10 horsepower when making 100 revolutions per minute will transmit 20 horsepower when making 200 revolutions per minute. We may, therefore,

say *the horsepowers transmitted by two shafts are directly proportional to the number of revolutions.*

EXAMPLES FOR PRACTICE.

1. What horsepower will a $2\frac{1}{4}''$ wrought-iron shaft transmit when running at 110 revolutions per minute, it being used for transmission only? Ans. 24.55 horsepower.

2. A $6''$ cast-iron shaft transmits 150 horsepower; how many revolutions per minute must it make, there being no pulleys between bearings? Ans. 62.5 R. P. M.

3. What should be the diameter of a wrought-iron shaft to transmit 100 horsepower at 150 revolutions per minute, there being pulleys between bearings? Ans. 6.82 in.

4. A certain line shaft is to transmit to a number of machines by means of pulleys between its bearings 65 horsepower when running at 150 revolutions per minute; what should be its diameter?
Ans. $3\frac{1}{4}$ in., nearly.

STEAM AND STEAM-BOILERS.

HEAT.

NATURE OF HEAT.

1970. Heat *is a form of energy.* It is the effect of a motion of the molecules composing matter. It has been stated in Mechanics that all matter is composed of molecules; now, these molecules are not in a state of rest, but are moving or vibrating back and forth with a greater or less velocity, and it is this movement of the molecules that causes the sensations of warmth or cold. If the motion is slow, the body appears cold to the touch; when the vibrations are rapid, the body becomes warm or hot.

1971. It was shown in Mechanics that a body in motion has kinetic energy, the amount of which is measured in foot-pounds by multiplying the weight of the body by the square of its velocity and dividing by 64.32. Since the molecules composing matter are in motion, they must possess kinetic energy, and we are justified, therefore, in saying that *heat is a form of energy.*

1972. Temperature is a term used to indicate how hot or cold a body is; i. e., to indicate the rate of vibration of the molecules of a body. A hot body has a high temperature; a cold body, a low temperature. When a body, as, for example, an iron bar, receives heat from any source, its temperature rises; on the other hand, when a body loses heat, its temperature falls.

1973. The temperature is *not* a measure of the quantity of heat a body possesses. *Temperature* may be considered to be a measure of the velocity of the molecules of a body as they vibrate to and fro, while the *quantity of heat* may

be considered to be the kinetic energy of the molecules composing the body. A small iron rod may be heated to whiteness and yet possess a very small quantity of heat. Its temperature is very high, which simply indicates that the molecules of the rod are vibrating with an extremely high velocity.

1974. Temperature is measured by an instrument called the thermometer, which is so familiar as to scarcely need description. It consists of a thin glass tube, at one end of which is a bulb filled with mercury. Upon being heated, the mercury expands in proportion to its temperature. Thermometers are graduated in different ways. In the Fahrenheit thermometer, which is generally used in this country, the point where the mercury stands when the instrument is placed in melting ice is marked 32°. The point indicated by the mercury when the thermometer is placed in water boiling in open air at the level of the sea is marked 212°. The tube between these two points is divided into 180 equal parts called degrees.

1975. Effects of Heat.—Suppose we take a vessel filled with some substance, say water. Let the vessel be a cylinder fitted with a piston, as shown in Fig. 647. The water is, say, at the freezing-point, and the millions of molecules composing the water are moving to and fro with a comparatively small velocity. Suppose the vessel is placed in a fire or furnace. Heat is communicated to the molecules of water, and they begin to move faster and faster. That is, their kinetic energy increases, and if a thermometer were inserted in the vessel it would be found that the temperature of the water rises. Consequently, one effect of heat is to raise the temperature of the body to which it is applied. But, after reaching a certain temperature, the molecules of the water not only move faster, but they move

FIG. 647.

farther from each other, and their paths are longer. It is plain that if the molecules are farther apart than they were originally, the whole body of them must take up more space. In other words, after reaching a certain temperature, the water expands as heat is added. Hence, another effect of heat is to expand bodies to which it is applied. Common examples of the expansion of bodies by heat are seen in the setting of tires, the expansion of the rails of a railway in summer, etc.

1976. The heat supplied to the vessel of water has so far done three things: (1) Raised the temperature of the water, and thus increased the kinetic energy of the molecules. Let the amount of heat expended for this purpose be denoted by S. (2) A certain quantity of heat has been used in expanding the water; that is, in pushing its molecules farther apart against the force of cohesion. Denote the amount of heat so expended by I. (3) Since the water expands, it must raise the piston P against the pressure of the atmosphere, and, consequently, more heat must be used to expand the water than would be required if there were no pressure on the upper side of the piston. Call this extra quantity of heat W.

If we denote by Q the total heat given up to the vessel of water, we have

$$Q = S + I + W.$$

Ordinarily, the greater part of the heat given to a body is spent in raising its temperature, and but little is used in expanding the body. That is, the quantity S is nearly equal to the quantity Q, while the quantities I and W are nearly nothing.

1977. Suppose that the piston is removed from the cylinder of Fig. 647, and a thermometer is inserted. As the vessel becomes more and more heated, the temperature indicated by the thermometer will rise until it reaches 212°. So far most of the heat has been used to raise the temperature of the water. But now, no matter how much heat is added to the water, the thermometer stands at 212°, and

can not be made to rise higher. This is the reason: When the temperature reaches 212°, the molecules of water have been set into such rapid motion that the force of cohesion is no longer able to hold them, and they tend to separate. In other words, the water is changing to a gas (steam), and all of the heat is being used to effect this change. The temperature of the steam will remain at 212° until all the water is changed to steam; then, if more heat is applied, the temperature of the steam will begin to rise.

Suppose we take a block of ice at a temperature of say 14°, and heat it. If a thermometer is placed in contact with the ice, its temperature will rise until it reaches 32°, and will then remain stationary. As soon as this temperature is reached, the ice begins to melt or change to water, and the heat, instead of raising the temperature farther, is all used to effect this change of state. Here, then, is another effect produced by heat. It will change a solid to a liquid, or a liquid to a gas.

1978. Latent Heat.—The heat which is expended in changing a body from the solid to the liquid state, or from the liquid to the gaseous state, is called *latent heat*. The portion of the heat applied which raises temperature, and which, therefore, affects the thermometer, is sometimes called **sensible heat.**

1979. Measurement of Heat.—Since heat is not a substance, it can not be measured directly in pounds or quarts; but, like force, it may be measured by the effects it produces. Suppose a certain quantity of heat raises the temperature of a pound of water from 52° to 53°, it will take the same quantity of heat to raise the temperature of a pound from 53° to 54°, and it will take double the quantity to raise the temperature of the pound of water from 52° to 54° that it took to raise the temperature from 52° to 53°. The unit quantity of heat is the quantity required to raise the temperature of a pound of water from 62° to 63°. This unit is called the **British thermal unit,** or B. T. U.

1980. Relation Between Heat and Work.—Suppose that, in the experiment shown in Fig. 647, the piston had been allowed to remain in the cylinder while the water was being changed to steam. Steam at 212° occupies nearly 1,700 times the space that the water originally occupied. Hence, the piston would be lifted in the cylinder to give room for the steam which was being formed. But to raise the piston requires work. Here, then, is an example of *work being performed by heat.* On the other hand, work will produce heat. If two blocks of wood are rubbed briskly together, they will become warm, and may even ignite. The work of friction causes the journals and bearings of fast-running machines to heat. A small iron rod may be heated to redness by pounding it on an anvil.

1981. Since work may be changed into heat, and heat into work, it seems probable that there is some fixed ratio between the unit of heat (B. T. U.) and the unit of work, the foot-pound. By a careful series of experiments, Dr. Joule, of England, discovered this ratio. He found that one B. T. U. is equal to 772 foot-pounds; later and more careful experiments show that 778 foot-pounds is more nearly correct. This number, 778 foot-pounds, is called the **mechanical equivalent** of one B. T. U.

We have, then, the following important law: *Heat may be changed to work, or work to heat; 778 foot-pounds of work are required to produce 1 B. T. U., and, conversely, the expenditure of 1 B. T. U. produces 778 foot-pounds of work.*

EXAMPLE 1.—The burning of a pound of coal gives out sufficient heat to raise 14,000 pounds of water from 62° to 63°. If all this heat is wholly utilized, how high will it lift a weight of 700 pounds?

SOLUTION.—Since 1 B. T. U. raises a pound of water from 62° to 63°, it requires 14,000 B. T. U. to raise 14,000 lb. of water from 62° to 63°. Hence, the burning of the pound of coal gives out 14,000 B. T. U. One B. T. U. is equivalent to 778 foot-pounds; hence, 14,000 B. T. U. are equivalent to $14,000 \times 778 = 10,892,000$ foot-pounds. Then, the height to which the weight can be raised is $10,892,000 \div 700 = 15,560$ feet. Ans.

EXAMPLE 2.—A cannon-ball weighing 60 pounds moves with a

velocity of 1,300 ft. per sec. Suppose the ball were suddenly stopped and its kinetic energy changed into heat. How many B. T. U. would be developed? If all this heat were applied to 100 pounds of water at a temperature of 60°, to what temperature would the water be raised?

SOLUTION.—By formula **113**, *Mechanics*, Part 1, the kinetic energy of the cannon-ball is $\frac{Wv^2}{64.32} = \frac{60 \times 1,300^2}{64.32} = 1,576,492$ foot-pounds. But 778 foot-pounds = 1 B. T. U. Therefore, the number of B. T. U. developed is $1,576,492 \div 778 = 2,026.3$ B. T. U. Since 1 B. T. U. raises the temperature of a pound of water 1 degree, it will take 100 B. T. U. to raise 100 pounds of water 1 degree. Hence, 2,026.3 B. T. U. will raise 100 pounds of water $2,026.3 \div 100 = 20.263°$, and the final temperature of the water will be $60° + 20.263° = 80.263°$. Ans.

1982. Specific Heat.—One B. T. U. raises the temperature of one pound of water one degree; will it have the same effect on a pound of mercury? Heat two one-pound iron balls to the temperature of boiling water, 212°; having now the same weights and temperatures, each ball has the same quantity of heat. Place one of these balls in a vessel, into which pour slowly enough water at a temperature of 60° that the iron will be cooled to 70° while the water is heated to the same temperature. Now, place the other hot ball in another vessel, into which pour mercury at a temperature of 60° until the iron and mercury reach a common temperature of 70°. In each case the hot ball was cooled from 212° to 70°; each, therefore, gave up the same quantity of heat. When, however, we consider its effects, we find that it raised less than ½ pound of water through a range of 10°, while 14½ pounds of mercury, nearly 30 times as much, was raised through the same range. It is plain, therefore, that to raise a pound of mercury from 62° to 63° requires $\frac{1}{30}$ the heat necessary to raise a pound of water from 62° to 63°. Hence, we say the *specific heat* of the mercury is $\frac{1}{30}$, or .0333.

The **specific heat** *of a body is the ratio between the quantity of heat required to warm that body one degree and the quantity of heat required to warm an equal weight of water one degree.*

EXAMPLE 1.—It is found that to raise the temperature of 20 pounds of iron from 62° to 63° requires 2.276 B. T. U. What is the specific heat of iron?

SOLUTION.—To raise 20 pounds of water from 62° to 63° requires 20 B. T. U. The specific heat of the iron is, according to the above definition, the ratio between the quantities of heat required to warm the iron and the water, respectively, through 1 degree; that is, it is the ratio 2.276 : 20 = 2.276 ÷ 20 = .1138. Ans.

EXAMPLE 2.—The specific heat of silver is .057. How many B. T. U. are required to raise 22 pounds of silver from 50° to 60°?

SOLUTION.—To raise the temperature of a pound of water 1 degree requires 1 B. T. U. Since the specific heat of silver is .057, only .057 B. T. U. is required to raise 1 pound of silver 1 degree. Hence, to raise 22 pounds of silver 10 degrees must require .057 × 22 × 10 = 12.54 B. T. U. Ans.

1983. Rule.—*To find the number of B. T. U. required to raise the temperature of a body a given number of degrees, multiply the specific heat of the body by its weight in pounds and by the number of degrees.*

Denote the number of B. T. U. required by U; the specific heat by c; the weight by W, and let t and t_1 be the temperatures before and after the heat is applied, respectively.

Then, $$U = c\,W\,(t_1 - t). \qquad \textbf{(136.)}$$

The specific heats of some of the more common substances are given in the following table:

TABLE 41.

Substance.	Sp. Heat.	Substance.	Sp. Heat.
Water	1.0000	Ice	.5040
Sulphur	.2026	Steam (superheated)	.4805
Iron	.1138	Air	.2375
Copper	.0951	Oxygen	.2175
Silver	.0570	Hydrogen	3.4090
Tin	.0562	Nitrogen	.2438
Mercury	.0333	Carbon monoxide	.2479
Lead	.0314	Carbon dioxide	.2170

1984. Latent Heat of Fusion.—This term is applied to the quantity of heat required to change a pound of a given substance from the solid to the liquid state. The only case of interest to the engineer is the heat required to change a pound of ice to water. Careful experiments show that about 144 B. T. U. are required to change a pound of ice at 32° to water at 32°. Hence, the latent heat of water is 144 B. T. U.

1985. The **latent heat of steam** is the quantity of heat required to change a pound of water at 212° into steam at 212°. Experiment shows that this quantity of heat is about 966 B. T. U. This shows that the heat required to change a pound of water at 212° to steam is 966 times as great as the quantity required to raise the temperature of a pound of water from 62° to 63°. The latent heat of steam is different for different temperatures.

EXAMPLE.—How many B. T. U. are required to change 5 pounds of ice at 15° into steam at 212°?

SOLUTION.—The heat units required to raise the temperature of the ice from 15° to 32° (the melting temperature) is, according to formula **136**,

$$U = c\,W(t_1 - t) = .504 \times 5 \times (32 - 15) = 42.84 \text{ B. T. U.}$$

To change the ice to water requires 144 B. T. U. for each pound, or $144 \times 5 = 720$ B. T. U. To raise the water from 32° to 212° requires, according to formula **136**,

$$c\,W(t_1 - t) = 1 \times 5 \times (212 - 32) = 5 \times 180 = 900 \text{ B. T. U.}$$

Finally, to change the water to steam requires 966 B. T. U. per pound, or $966 \times 5 = 4{,}830$ B. T. U. Therefore, in all, $42.84 + 720 + 900 + 4{,}830 = 6{,}492.84$ B. T. U. are required. Ans.

Expressed in foot-pounds, the work required to effect the above change would be $6{,}492.84 \times 778 = 5{,}051{,}429.5$ foot-pounds, or work enough to lift a weight of 1,000 pounds nearly a mile.

1986. Since a pound of ice requires 144 B. T. U. to change it to water, it follows that when a pound of water at 32° changes to ice (freezes), 144 B. T. U. are given out in the process. Similarly, the condensation of a pound of

steam into water at 212° liberates 966 B. T. U. This principle is applied in heating buildings by steam. The steam passes through the radiators and condenses. The latent heat thus set free warms the building.

1987. Temperature of Mixtures.—It is often desirable to calculate the final temperature of a mixture of different substances at different temperatures. The following law is to be observed in such cases: *The quantity of heat in a mixture is the same as the quantity of heat contained in the substances before being combined.* If two substances of different temperatures are placed together, they both finally attain the same temperature; the heat lost by the one in coming from a higher to a lower temperature is gained by the other in passing from a lower to a higher temperature.

Rule.—*To find the temperature of a mixture of several substances, multiply together the weight, specific heat, and temperature of each substance separately, and add the products. Next, multiply together the weight and specific heat of each of the substances separately, and add these products. Divide the former sum by the latter. The result will be the temperature of the mixture.*

Let $w, w_1, w_2 \ldots\ldots$ = weights of the several substances, respectively;
$c, c_1, c_2 \ldots\ldots$ = specific heats of the substances, respectively;
$t, t_1, t_2 \ldots\ldots$ = temperatures of the substances, respectively;
T = final temperature of mixture.

Then,
$$T = \frac{w\,c\,t + w_1 c_1 t_1 + w_2 c_2 t_2 + \ldots\ldots}{w\,c + w_1 c_1 + w_2 c_2 + \ldots\ldots}. \qquad (137.)$$

EXAMPLE.— 15 pounds of water at 42° and 30 pounds of mercury at 70° are placed in the same vessel, and a ball of lead weighing 19 pounds and having a temperature of 110° is immersed in the mixture. What will be the final temperature of the contents?

SOLUTION.—Applying formula **137**,

$$T = \frac{15 \times 1 \times 42 + 30 \times .0333 \times 70 + 19 \times .0314 \times 110}{15 \times 1 + 30 \times .0333 \times 19 \times .0314} = 46.13°. \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE.

1. A body weighing 143 pounds falls 62 feet. If the energy of the body at the end of the fall be changed into heat, how many B. T. U. will be developed? Ans. 11.39 B. T. U.

2. An expenditure of 210 B. T. U. per minute will develop how many horsepower? Ans. 4.95 H. P.

3. Supposing $\frac{1}{7}$ of the total heat of the coal to be used in doing work, how many pounds of coal must be burned per hour to run a 40 horsepower engine? Each pound of the coal gives out 13,500 B. T. U. Ans. 52.8 lb.

4. From what height must a block of ice fall, that the heat developed by its collision with the earth may be just enough to melt it, supposing that all of the energy gained during the fall is converted into heat? Ans. 112,032 feet.

5. A bar of iron weighing 20 pounds and having a temperature of 350° is plunged into a tank containing 130 pounds of water at 55°. To what temperature will the water be raised? Ans. 60°.

6. How many pounds of ice at 32° can be melted by 3 pounds of steam at 212°? Ans. 23.875 lb.

SUGGESTION.—Each pound of ice requires 144 B. T. U. to melt it; each pound of steam in changing to water at 32° gives up 1,146 B. T. U. (See Art. **1999.**)

7. How many B. T. U. are required to raise the temperature of 26 pounds of copper from 57° to 93°? Ans. 89.1 B. T. U.

STEAM.

PRELIMINARY IDEAS.

1988. **Steam** is *water vapor;* that is, it is *water* changed into a *gaseous state* by the application of *heat.*

The process of changing water (or other liquid) into vapor by means of heat is called **ebullition,** or **boiling.**

1989. When a vessel containing water is placed in contact with a flame of fire, the air which is generally contained in the water is first driven off and escapes from the surface without noise. The molecules of the water which are in contact with the part of the vessel nearest the fire receive heat first, and begin to move more and more rapidly until, finally, the cohesion between them is overcome, and they rise into the main body of water. At last, the whole mass of water becomes heated through, and the molecules are

then able to rise through the body of the water, overcome the pressure on the surface of the water, and escape in the form of a gas. Then the water boils.

1990. It is plain that if the pressure on the surface of the water is increased, it will take more work to force the molecules to the surface against the increased pressure. That is, more heat must be expended upon the water to make it boil, and, therefore, the boiling-point will be raised. We have seen that when water boils in open air, exposed, therefore, to the atmospheric pressure of 14.7 lb. per sq. in., the water boils when it reaches a temperature of 212°. If the pressure on the surface is increased to say 32 lb. per sq. in., the water will not boil until it reaches a temperature of 254°. On the other hand, if the pressure is lowered to 6 lb. per sq. in., the water boils when it reaches 170°. Hence, we have the following law:

An increase of pressure on the surface of a liquid raises the temperature at which it boils; a decrease of pressure lowers the temperature at which it boils.

1991. When steam is in contact with the water from which it is generated, it is called **saturated steam.** This is the condition of steam in a boiler. According to the law just given, the temperature of saturated steam depends upon the pressure only. When the steam in a boiler shows a gauge pressure of 60 pounds, its temperature *must be* 307°. A thermometer placed in a boiler could be used to tell the pressure of the steam. It would be even more accurate (though not as convenient) than a steam-gauge.

1992. Steam, if not in contact with water, may be heated like air or any other gas until its temperature is higher than the boiling-point. For instance, let a quantity of water be placed in a cylinder as shown at *a*, Fig. 648. Suppose, for convenience, that the area of the cylinder is 100 sq. in.; then, the pressure of the atmosphere upon the piston is $14.69 \times 100 = 1{,}469$ lb. The number 14.69 is a little more exact than 14.7.

1993. When a part of the water is changed to steam, as shown at *b*, Fig. 648, the steam is in a saturated state, and its temperature is 212°. When, however, the water is all changed to steam, as shown at *c*, any further addition of heat will raise the temperature of the steam, while the pressure will, of course, remain at 14.69 lb. per sq. in. Steam in this condition is said to be **superheated steam.** The specific heat of superheated steam is .4805, or say .48

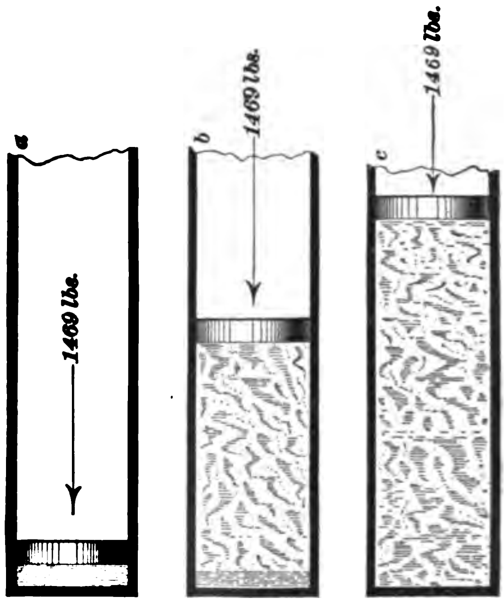


FIG. 648.

for ordinary purposes. Hence, .48 of one B. T. U. is required to raise the temperature of superheated steam one degree. The temperature of saturated steam can not be raised if the pressure remains constant. All the heat is expended in changing water to steam, and until all the water is vaporized the temperature remains constant.

1994. Prime or wet steam is steam which contains a certain percentage of water in suspension or mixed with it. If steam rises from the surface of water with a velocity greater than 2.5 feet per second, it carries water with it in

the form of spray, and when such fine spray has been once entrained or carried up with the steam, it does not readily settle against the rising current of the new steam that is constantly being formed. Steam has been known to hold 16 times its own weight of water in suspension, or to be 1,600 per cent. moist; in the usual practice, however, the priming of steam-boilers falls within the range of from 5 to 15 per cent.

1995. Gauge and Absolute Pressures.—It has been shown that the pressure of the atmosphere is 14.7 pounds per square inch above vacuum. Ordinary gauges register pressures above atmosphere only. Thus, if the steam-gauge of a boiler shows 80 pounds pressure, it indicates that the pressure of the steam in the boiler is 80 pounds per square inch greater than the pressure of the atmosphere. To find the pressure of the steam above vacuum, we must, therefore, add 14.7 to the gauge-reading; thus, $80 + 14.7 = 94.7$. The pressures indicated by the gauge are called **gauge pressures**; pressures above vacuum are called **absolute pressures.** To obtain the absolute pressure, add 14.7 to the gauge pressure.

PRESSURE AND TEMPERATURE OF STEAM.

1996. Having given the gauge pressure or the pressure above the atmosphere in a boiler, to determine the temperature of the steam and water within the boiler:

Rule.—*To 199 add 14 times the square root of the pressure. The result will be in Fahrenheit degrees.*

Let t = temperature of steam;
p = gauge pressure of steam.

Then, $$t = 199 + 14\sqrt{p}. \qquad \textbf{(138.)}$$

EXAMPLE.—The pressure in a boiler is 81 pounds per square inch above the atmosphere, as shown by the steam-gauge; what is the temperature of the steam in the boiler?

SOLUTION.— $t = 199 + 14\sqrt{81} = 325°$ Fahrenheit. Ans.

1997. Having given the temperature of the steam and water within a boiler in Fahrenheit degrees, to determine the pressure within the boiler:

Rule.—*Subtract 199 from the temperature, and divide their difference by 14. The square of this quotient will be the pressure within the boiler in pounds per square inch above the atmosphere;*

or, $$p = \left(\frac{t - 199}{14}\right)^2. \qquad \textbf{(139.)}$$

EXAMPLE.—The temperature of the steam within a boiler is 325° F.; what is the pressure in the boiler?

SOLUTION.— $p = \left(\frac{325° - 199}{14}\right)^2 = 81$ pounds per square inch above atmospheric pressure, or $81 + 14.7 = 95.7$ pounds per square inch above a vacuum. Ans.

PROPERTIES OF STEAM.

1998. The **total heat of vaporization** is the number of heat units required to change a pound of water at 32° F. to steam of the given temperature and pressure.

1999. Having given the temperature of the steam within a boiler in Fahrenheit degrees, to determine the total heat of vaporization of 1 pound of the saturated steam in the boiler from water at 32° F.:

Rule.—*Add 1,081.4 to the product of the given temperature of the steam and .305. The result will be the number of British thermal units required to convert 1 pound of water at 32° F. into 1 pound of steam at the given temperature.*

Let $H =$ total heat of vaporization in B. T. U.;
$t =$ temperature of steam.

Then, $$H = 1{,}081.4 + .305\,t. \qquad \textbf{(140.)}$$

EXAMPLE.—What is the total heat of vaporization of one pound of saturated steam at 325° F.?

SOLUTION.— $H = 1{,}081.4 + .305 \times 325 = 1{,}180.5$ B. T. U. Ans.

2000. The **temperature** of saturated steam does not increase by equal increments for equal advances in pressure, but rises in a decreasing ratio. For example, at

atmospheric pressure an added pound in the steam pressure means a gain of 3.5° F. in the temperature, while at 150 pounds pressure per square inch, it means but an increase of .5° F. in temperature.

2001. The **total heat of vaporization** of steam increases but slowly with the increase in the pressure and temperature, and it takes but 1.07 times as much heat to produce a pound of steam at 485 pounds per square inch gauge pressure as it does to produce a pound under atmospheric pressure.

EXPANSION OF STEAM.

2002. Experiment has shown that when a given amount of saturated steam at a given pressure, and enclosed in a cylinder, is allowed to expand, its absolute pressure will decrease very nearly inversely as its volume increases, and that it will very closely retain its saturated state, although there will be some condensation. In other words, steam in expanding approximately follows Mariotte's law. (See Art. **852,** *Gases Met With in Mines.*)

EXAMPLE.—An engine cylinder contains 1½ cubic feet of steam at a pressure of 65.3 pounds per square inch, gauge. If the steam expands until the volume is 6 cubic feet, what will be the final gauge pressure?

SOLUTION.—Initial absolute pressure $= 65.3 + 14.7 = 80$ pounds per square inch.

According to Mariotte's law

$$p_1 = \frac{80 \times 1.5}{6} = 20 \text{ pounds per square inch, absolute.}$$

$20 - 14.7 = 5.3$ pounds per square inch, gauge. Ans.

COMBUSTION AND FUELS.

2003. **Combustion** is the *rapid* chemical combination of various *substances* with *oxygen*, as a result of which heat and light are produced.

2004. Atmospheric air is the chief source of supply from which the oxygen used in the combustion of fuels is drawn. It is composed of a mixture of oxygen and nitrogen

in the proportion of 1 pound of oxygen to 3.35 pounds of nitrogen; or, by volume, 1 cubic foot of oxygen to 3.76 cubic feet of nitrogen. Therefore, for every pound of oxygen employed in combustion, 4.35 pounds of air must be supplied, or for every cubic foot of oxygen, 4.76 cubic feet of air must be supplied. Nitrogen, however, takes no part in combustion, and, whenever present, passes off as a free gas, heated up to the temperature of the other gases with which it is mixed.

The volume of 1 pound of
Air at 62° F. is..................13.14 cubic feet.
Oxygen at 62° F. is..............11.89 cubic feet.
Nitrogen at 62° F. is.............13.50 cubic feet.

2005. **Fuels** are those forms of matter which are chiefly composed of the combustible elements, *carbon* and *hydrogen*. Coal, coke, wood, and petroleum are examples of fuels, but of these, coal is by far the most generally used in the furnaces of boilers for the production of steam.

2006. The temperature at which a combustible element or fuel takes fire, when brought into the presence of oxygen or air, differs for each substance considered, although it is a constant for any one form of matter. For example, sodium ignites and enters into chemical combination with the air at ordinary temperatures, while, in order to light an illuminating gas jet with a piece of heated iron, the iron would have to be heated to an orange color, or a temperature of about 2,000° F.

2007. Hydrogen, in whatever form it may appear, will always separate and combine with *oxygen*, when ignited, in the proportion of 1 pound of hydrogen to 8 pounds of oxygen to produce steam, in which form it will pass off and condense into 9 pounds of water; during the time it is being completely burned, 62,032 B. T. U. will be generated.

2008. The combustion of *carbon*, in like manner, is always complete at first; that is to say, 1 pound of carbon combines with 2.66 pounds of oxygen to form 3.66 pounds

TABLE 42.

One Pound of Combustible.	Theoretical Weight of Gas, in Pounds, Required to Effect the Complete Combustion of One Pound of Combustible.		Actual Weight of Air, in Pounds, Required to Effect the Complete Combustion of One Pound of Combustible.		Total Heat of Combustion of One Pound of Combustible in B. T. U.	The Equivalent of the Total Heat of Combustion, Expressed in the Number of Pounds of Water under Atmospheric Pressure it would Evaporate.	
	Oxygen.	Air.	With Chimney Draft, and Initial Temperature of Air at 62° F.	With Forced Draft at 62° F., and Waste Gases at 320° F.		From 62° F. and at 212° F.	From and at 212° F.
	1	**2**	**3**	**4**	**5**	**6**	**7**
Hydrogen	8.00	34.8	70	47	62,032	55.6	64.0
Carbon (completely burned)	2.66	11.6	22	15	14,500	13	15
Coal (of average composition)	2.46	10.7	21	14	14,133	12.67	14.63
Coke	2.50	10.9	22	15	13,550	12.14	14.02
Wood (average kiln-dried)	1.40	6.10	12	18	7,792	6.98	8.07
Petroleum	3.54	11.9	31	21	20,408	18.83	21.18

of *carbonic acid gas;* but if the supply of oxygen should be insufficient in quantity to combine with all the carbon present, and at the temperature of ignition, the carbonic acid gas will give up part of its oxygen, and reduce the final union of the two elements to the proportion of 1.33 pounds of oxygen to 1 pound of carbon to form 2.33 pounds of carbonic oxide gas.

The complete combustion of 1 pound of carbon to carbonic acid gas generates 14,500 B. T. U., but if the combustion be incomplete, that is, if the final product of the combustion is carbonic oxide gas, only 4,450 B. T. U. will be generated. If, however, this carbonic oxide gas should come in contact with more air, it will immediately ignite and combine with another 1.33 pounds of oxygen to form 3.66 pounds of carbonic acid gas again, and will regenerate the 10,050 B. T. U. which had previously been lost.

2009. In Table 42 the more important quantities that have to be considered in connection with combustibles have been tabulated; to illustrate the uses to which the table may be put, we will consider a short example.

EXAMPLE.—A furnace has a grate area of 36 square feet, upon which 453.6 pounds of coal are burned per hour, under an ordinary chimney draft. How many pounds of air must pass through the grate per minute to effect the complete combustion of the coal?

SOLUTION.—Since 453.6 pounds of coal are burned per hour, $453.6 \div 60 = 7.56$ pounds will be consumed per minute, and from column 3, Table 42, we find that 21 pounds of air will be required per pound of coal; therefore, $7.56 \times 21 = 158.76$ pounds of air will have to pass through the grate per minute. Ans.

EXAMPLE.—In the last example, (*a*) what will be the velocity of the air through the grate, if we assume its temperature just before entering the furnace to be 62° F.; (*b*) what will be the total heat per hour generated by the complete combustion of the coal; (*c*) if no heat is lost, what amount of water will this heat evaporate from and at 212° F.?

SOLUTION.—(*a*) By referring to Art. **2004,** we find the volume of 1 pound of air at 62° F. to be 13.14 cubic feet; therefore, the total volume of the air that will pass through the grate per minute will be $158.76 \times 13.14 = 2,086.1$ cubic feet, and, dividing this by the area of the grate, we get $2,086.1 \div 36 = 57.95$ feet per minute as the velocity of the air through the grate. Ans.

(*b*) The total heat of combustion of 1 pound of coal is 14,133 B. T. U. (see column 5, Table 42); therefore, $453.6 \times 14,133 = 6,410,728.8$ B. T. U. will be generated in the furnace per hour. Ans.

(*c*) From column 7 of Table 42, we find the equivalent evaporation of 1 pound of coal to be 14.63 pounds of water from and at 212° F.; therefore, 453.6 pounds of coal would evaporate $453.6 \times 14.63 = 6,636.168$ pounds of water per hour. Ans.

STEAM-BOILERS.

TYPES OF BOILERS.

2010. A **steam-boiler** is an apparatus for the production of steam under pressure by the expenditure of the heat energy stored in fuel.

The general principles involved in all the various boiler designs are necessarily the same, although they have assumed a variety of different forms in the effort on the part of engineers to meet the varying conditions under which boilers have to be operated.

For this reason, it has become necessary to classify them by the marked peculiarities of construction which some of the more common makes possess, and we will, therefore, take up their discussion along the natural line of their development, and under the following heads: (1) Plain Cylindrical Boilers; (2) Flue-Boilers; (3) Tubular Boilers; (4) Water-Tube Boilers.

PLAIN CYLINDRICAL BOILERS.

2011. A plain cylindrical boiler is simply a long hollow cylinder made of wrought-iron or steel plates riveted together, after having been bent into the required shape. It is usually fitted with flat cast-iron heads, as shown in Figs. 649 and 650, although in some cases the heads are made hemispherical or "egg" ended, since this form offers the greatest possible resistance to bursting.

When such a boiler is in operation, the iron cylinder or shell, should be kept about two-thirds full of water, and that this may be done, a feed-water pipe *N*, leading into the boiler below the water-line *V*, Figs. 649 and 651, must be provided.

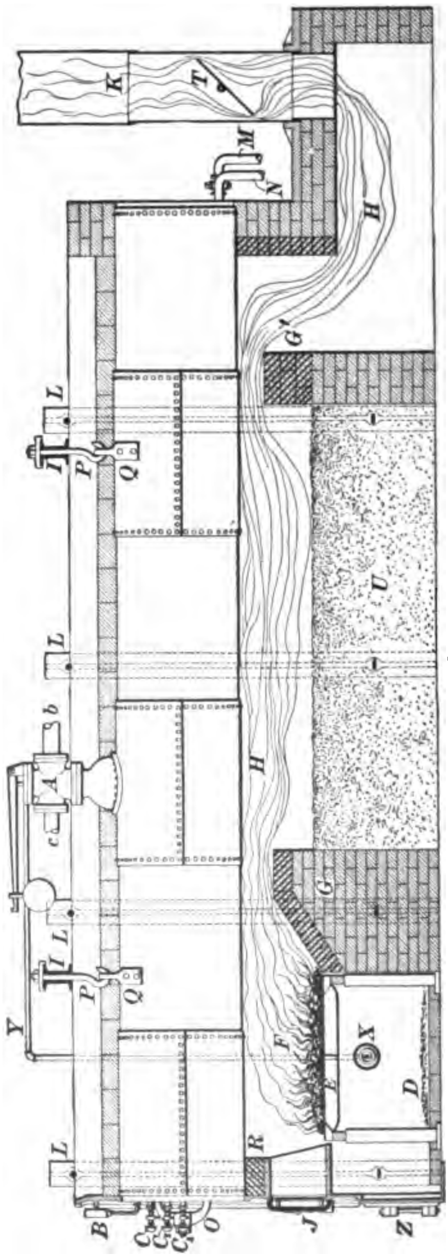


Fig. 649.

By means of this pipe, water can be forced into the boiler from time to time to supply the place of that which is evaporated into steam.

In order to be able to tell when the water in the boiler has reached its proper level, three *water-cocks* C, C_1, C_2 are placed one above the other, usually on the head of the boiler, where they will be handy to get at; they are so arranged that the middle one will come in line with the water-line V, Fig. 651, while the upper one enters the steam-space S, and the lower one the water-space W. When, therefore, the water is at its proper level, and the cocks are opened, steam should come out of the upper one, a mixture of steam and water out of the middle one, and pure water out of the lower one.

2012. The device at A is a safety-valve, a sectional view of which is given in Fig. 652. The nozzle at S communicates directly with the boiler, and the steam has a free passage through which to flow past the valve V to the steam-pipe, bolted on to the nozzle O. When, however, the steam in the boiler rises above the pressure the boiler is to carry, the valve V is lifted from its seat against the resistance offered by the lever L and weight W, through the stem P, and the steam is permitted to escape outside through the relief orifice

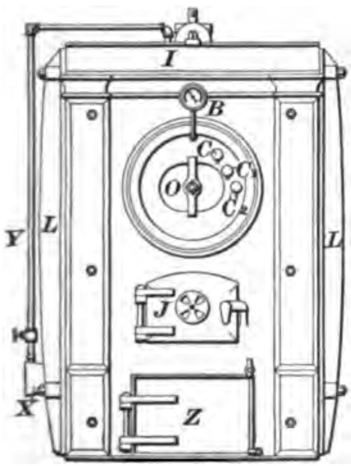


FIG. 650.

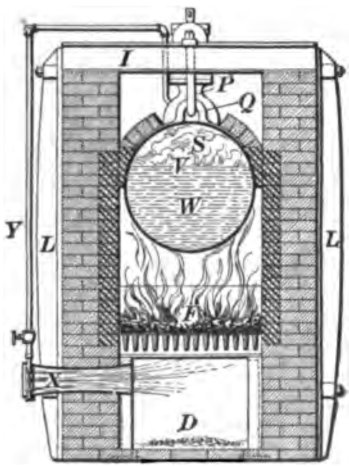


FIG. 651.

at R, until the pressure falls to its normal value. The pipe c, Fig. 649, is attached to this orifice to conduct the steam away as it escapes from the safety-valve.

The same explanation describes the second safety-valve shown in Fig. 653, which differs from the first one only in not having the additional nozzle for connecting the steam-pipe. Therefore, when this form of safety-valve is used, the steam must be led from the boiler through a pipe connected at some other point.

2013. The steam-gauge B, Fig. 650, is an instrument having a circular face and a pointer to indicate the pressure in pounds per square inch in a boiler. It should in all cases be mounted on every boiler, as it enables the engineer to see

at a glance whether the boiler is generating a greater or less amount of steam than the circumstances require. The gauge is connected to the boiler by a pipe.

2014. In generating the heat for the evaporation of

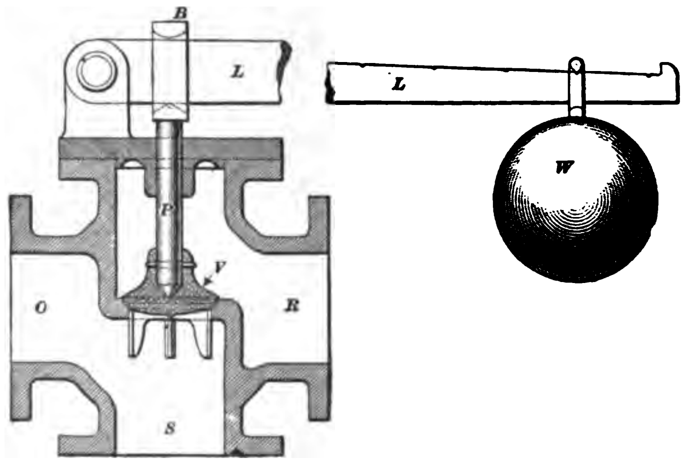


FIG. 652.

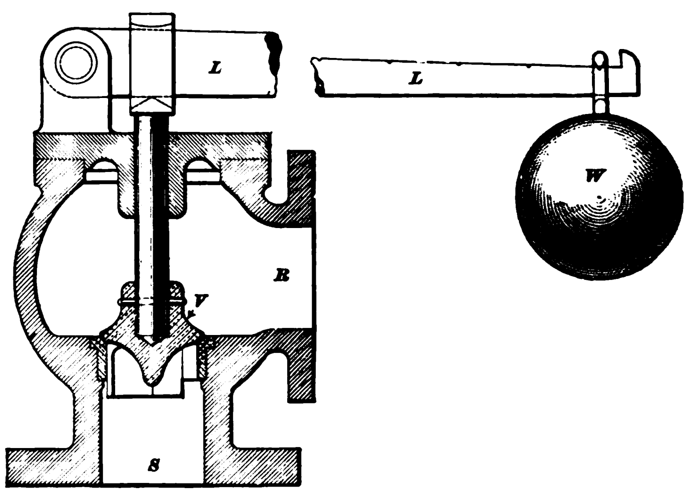


FIG. 653.

the water in these boilers, they are always externally fired; that is to say, the furnace, which is made chiefly of brick-

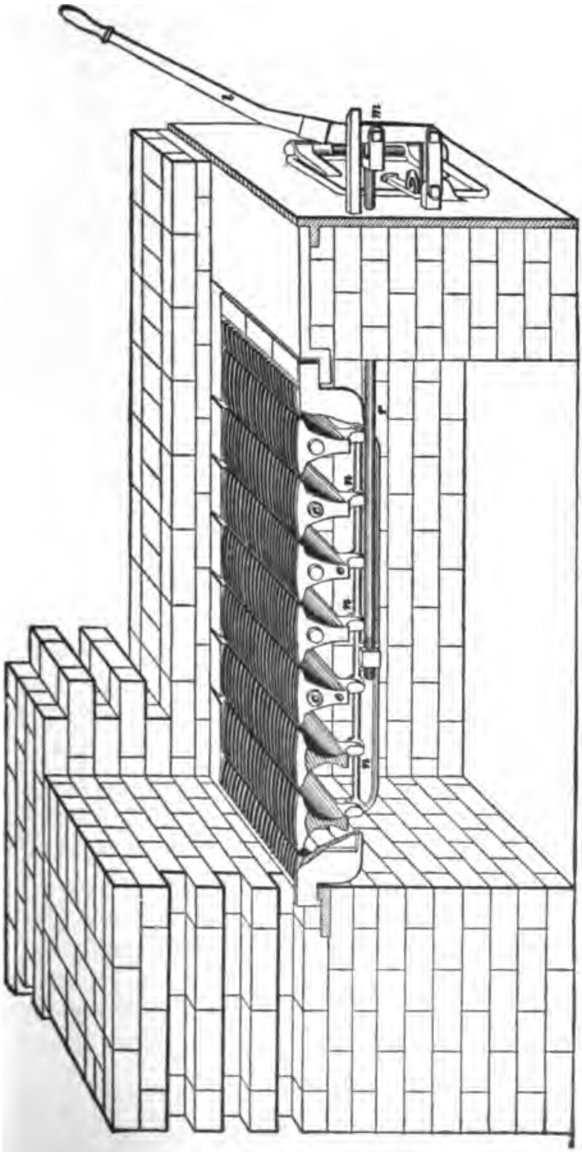


FIG. 654.

work, is built up under one end of the shell, and is also made to form a part of the masonry enclosing the whole boiler to prevent the heat from radiating

2015. When the boiler is in operation, the fuel which is thrown in through the furnace-door *J* ignites and burns on the furnace-grate *E*, Fig. 649. The furnace-grate is frequently made up of parallel layers of cast-iron grate-bars placed a short distance apart, which rest on iron supports placed in the masonry. There are, however, a great many different designs of grate-bars in use, both of the stationary as well as of the rocking types. In Fig. 654 is shown one of this latter kind, known as the McClave Rocking Grate. The grate-bars *e*, *e*, *e*, made in the form of very deep **T**'s, are pivoted at both ends, and when the lever *l* is worked backwards and forwards, the rod *r*, being connected with *l* at *m*, and also with *e*, *e*, *e* at *n*, *n*, *n*, transmits the motion of the lever to the grate-bars, and causes them to rock backwards and forwards about their centers of rotation *c*, *c*.

By means of these rocking grates, fires can be cleaned or shaken down without opening the furnace-doors—a very desirable feature, since, whenever these doors are opened, the volume of cold air that rushes in over the grate tends to chill the fire and lower the temperature of the furnace.

2016. Returning again to Figs. 649 and 651, the ashes of the burning fuel fall through these grate-bars into the ash-pit *D*, and are removed through the door *Z*, while the hot gases generated by the burning coal pass upwards through the combustion-chamber *F*, and are led in close contact with the shell over the bridge-walls *G*, *G'*, and through the flue-passages *H*, *H* to the smokestack *K*. The ashes *U* placed beneath the boiler are for the purpose of bringing the heated gases in contact with the bottom of the boiler.

In order to provide for the proper cleaning of the whole structure, a blow-off pipe *M*, through which the water may be drained off, is led from the boiler, and a manhole *O*,

Fig. 650, closed with a manhole plate, yoke, and bolt, as shown, makes it possible for the fireman to remove the sediment and coating which from time to time are deposited in the shell by the evaporating water. Doors opening into the flues, etc., through the brickwork below the boiler also facilitate this cleaning process.

2017. Various means are employed for "setting" or supporting boilers in position. Care must be taken to so arrange the supports that the boiler-shell will be free to expand and contract with the changes of temperature.

In Figs. 649 to 651, the boiler is hung from wrought-iron channel-beams *I*, which rest upon the enclosing masonry work, and, whenever the plates expand or contract, the boiler swings a little on the hooks, one way or the other.

To add rigidity to the brick walls, buckstaves *L*, *L* are provided, which are bolted or keyed together above and below the boiler by long rods.

2018. In these boilers, as well as in all others, the furnace gases, when in their highly heated state, should be kept from coming in contact with those metal parts of the boiler which lie above the water-line *V*, since they tend, by overheating the metal, to cause a blistering of the plates and a burning off of the rivet-heads, that in time would produce serious leaks, if not an explosion. To prevent this, the masonry is made to abut against the boiler-shell just below the water-line, as seen in Fig. 651, and is frequently arched completely over the shell as well, for the purpose of diminishing the heat radiation from the metal parts of the boiler. All the masonry with which the flame does not come in contact is generally made of ordinary red brick or stone, while that with which the flame does come in contact is made of firebrick.

2019. The draft or rapidity with which the air flows through the grate of a boiler, for the purpose of supplying the fuel with a sufficient quantity of oxygen to insure its complete combustion, is usually produced by the chimney

or smokestack, although it is frequently increased and made more efficient by connecting a blower with the ash-pit *D*.

There are a great many different kinds of these blowers, but the simplest and the one best adapted for boiler work is that represented in Figs. 649 to 651, at *X*. It consists simply of a long metal cylinder into which a jet of steam is led from the boiler by a $\frac{3}{4}$-inch pipe.

The steam, as it rushes through the pipe *Y* into the blower with great velocity, draws the air along with it, and the cylinder, by giving the blast the proper direction, causes it to impinge on the grate-bars *E*; thus a rapid and complete combustion of the coal is produced.

2020. Plain cylindrical boilers are little used at the present day, except in mining districts and other localities where fuel is very cheap, for they have so small a water-heating area, in proportion to the amount of water they contain, and the volume of gas given off from their furnaces, that they are very wasteful of heat energy. They are made from 28 to 50 inches in diameter, and from 20 to 60, and even 100, feet in length. This great length is given to increase the water-heating area.

FLUE-BOILERS.

2021. The flue-boiler represents a type in which an increased water-heating area is obtained by the introduction of one or two large flue-pipes within the boiler-shell, below the water-line. In Figs. 655 to 657 is shown an ***externally fired flue-boiler***, or one in which the heated gases, after passing from the furnace, over the bridge-walls, and along in contact with the lower surface of the boiler till the space *H* is reached, are made to return through one or two large flues *A*, *A*, Fig. 657, fitted within the cylinder below the water-line.

From these flues the gases enter the smokebox *B*, and flow from there directly into the smokestack *C*. The arrangement of the masonry and the "setting" of the boiler-shell, in this instance, follows the construction of Figs. 649 to 651 so closely that no further explanation need be

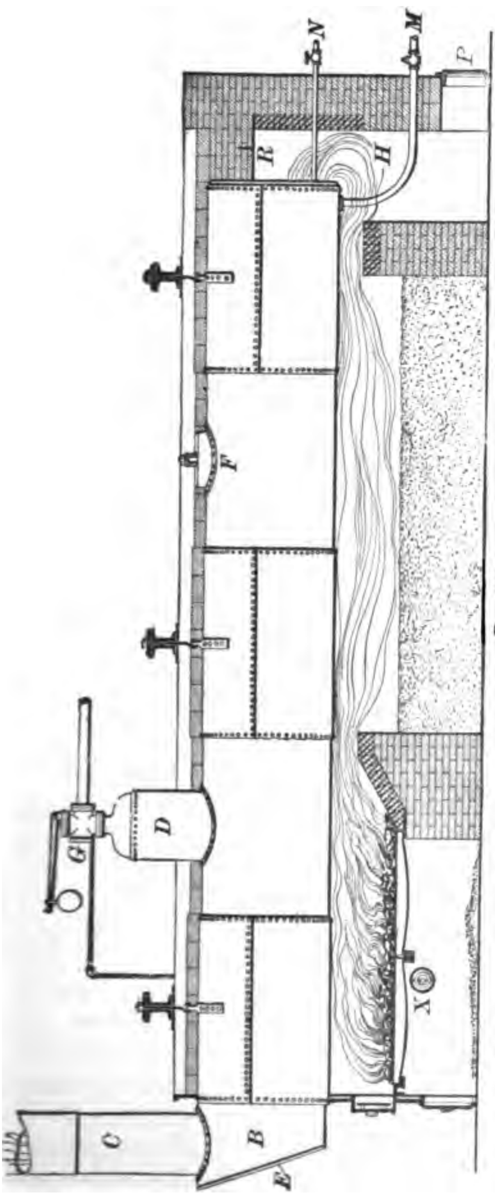


FIG. 655.

given, other than to call attention to the feed-pipe at *N*, the blow-off pipe at *M*, the steam-gauge at *K*, the gauge-cocks on the column *L*, and the steam-dome placed above the boiler at *D*. The steam-gauge and the gauge-cocks communicate with the boiler through the pipes *s* and *t*, the former passing into the steam-space and the latter into the water.

2022. There is generally a steam-dome on every boiler, which serves as a chamber in which the steam collects and is dried or relieved of a portion of its entrained water before passing to the engine. The hole in the shell of the boiler, over which the steam-dome is riveted,

should not be made larger than is sufficient to permit the free passage of the steam. Anything greater than this only weakens the shell, without adding to the utility of the dome.

To facilitate the cleaning of the flues and boiler, a door is provided in the smokebox at *E*, and a manhole in the shell at *F*. A door should also be made in the masonry work to enable the fireman to get at the external flues of

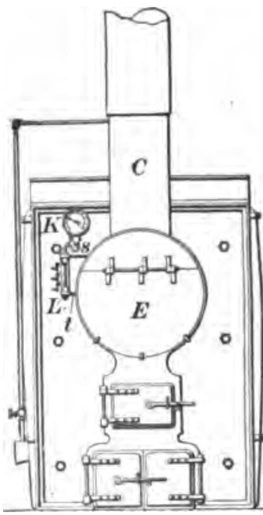


FIG. 656.

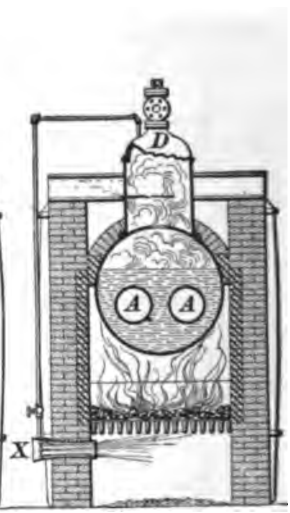


FIG. 657.

the structure. Access is given to the rear end of the shell and to the pipes *M* and *N* through the door *P*. The cast-iron plate *R* supports the brickwork over the space *H*. The furnace of this boiler is supplied with the same form of steam-jet blower *X* as that described in connection with Fig. 649.

2023. In Fig. 658 a design of an *internally fired flue-boiler* is shown.

In this type, the furnace is entirely surrounded by water, and the bridge-wall *D*, the grate *C*, and the ash-pit *P* are placed within the flue. If these flues (only one of which is shown in the figure) are corrugated, their capacity for resist-

ing external pressure is greatly increased over that of the plain flue; they are, consequently, much less liable to collapse or to be pushed in. Above the flue, and surrounded by water, are a large number of tubes leading from the chamber *E* through the shell to the smokebox *F*, which are provided to convey the heated furnace gases a second time through the water after they have traversed the corrugated flue.

The tubes *B*, besides greatly increasing the heating surface of the boiler, combine with the flue and stayrods *G* to

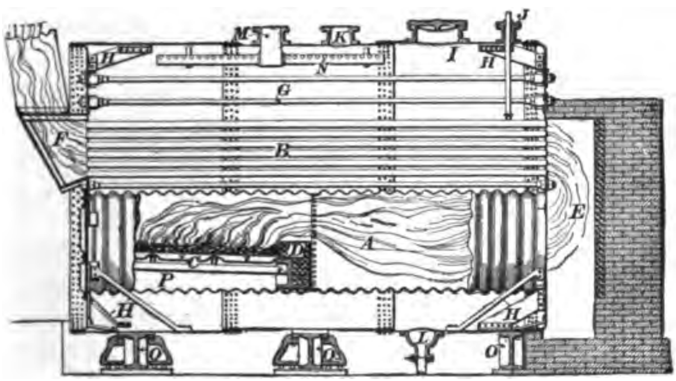


FIG. 658.

increase the strength of the boiler-heads, since when the boiler is in operation the internal pressure puts them under a tensional strain. Further stiffness is given to the boiler by riveting a number of plates *H*, *H* (called *gusset-stays*) around the head and inner surface of the shell.

To facilitate the inspection and cleaning of the interior of the shell, a cast-iron manhole *I*, closed by a bolted cover, is riveted on the upper surface of the boiler, and for cleaning the tubes *B* a door is provided to the smokebox *F*. The smokestack is led from the opening in the top of the smokebox *F*.

The setting of this boiler is somewhat different from those previously considered. The masonry is simply built up to prevent heat radiation, and to insure the flow of the furnace

gases through the return tubes *B* of the boiler. The curved beams *O*, *O*, *O* support the boiler.

The steam-gauge and water-cocks are not shown in this figure. The safety-valve should be bolted on at *K*, and the blow-off pipe at *L*. The feed-pipe *J* leads into the steam-space, and discharges below the tubes *B*. The steam supply is drawn from the nozzle *M*, through the pipe *N*. The pipe *N* is made to take the place of a steam-dome, since the steam, in passing through the small holes of the pipe, is freed from the greater part of its entrained water.

Flue-boilers, when properly designed and constructed, give very good working results, and have given good satisfaction among English engineers. In America, they are not so popular as some of the other makes, although they are found in operation at a number of plants.

TUBULAR BOILERS.

2024. Tubular boilers, as in the case of flue-boilers, may be divided into two classes, the ***internally fired*** and ***externally fired***. The internally fired boiler shown in Fig. 659

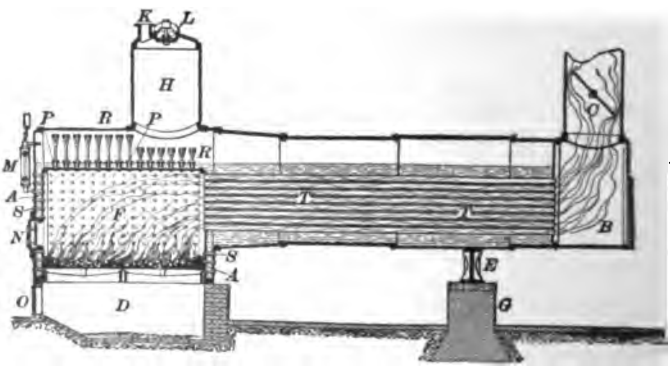


FIG. 659.

is called the **fire-box or locomotive boiler.** This type of boiler, next to the multitubular boiler, is probably more used than any other type. It is used exclusively in railway service, and also largely as a stationary boiler. A large pro-

portion of the small portable combined engines and boilers used for agricultural purposes have the fire-box type of boiler. The general construction of this type of boiler is shown in Fig. 659. The shell is composed of two differently shaped parts riveted together. The front part of the shell is cylindrical; the rear part is usually of a rectangular cross-section with vertical sides, or of a trapezoidal section with inclined sides; in either case, the top is semicylindrical. The furnace F is a box of the same shape as the rear end of the shell in which it is placed. There is a space left between the sides and end of the furnace and the shell; this space is filled with water, as shown at A, A. A series of tubes extend from the front sheet of the furnace or fire-box to the front head of the shell. The shell is prolonged beyond the front head, forming a smokebox B, into which opens the stack C.

As shown in this figure, the *water-legs* (as the spaces A, A are called) only extend down as far as the grate, the ash-pit D being formed in the brick-setting. In many boilers of this type, the water-legs extend down to the bottom of the ash-pit, and sometimes there is a water-space below the ash-pit; that is, the furnace and ash-pit are entirely surrounded by water.

The boiler is supported at the front end by the cast-iron cradle E resting upon the masonry foundation G. The rear end is supported upon a brick wall, which also forms the ash-pit. The boiler is usually provided with a dome H, from which is led the main steam-pipe, which is bolted on at K. In the figure, the dome is provided with a manhole L. The feed-water may be introduced at any convenient point in the shell. The pressure-gauge, water-glass, and gauge-cocks are attached to the column M, which is placed in communication with the interior of the shell. The furnace and ash-pit doors are shown at N and O, respectively. The safety-valve is usually attached to the dome.

Since the flat sides of the furnace and shell are liable to bulge on account of the pressure, they must be braced or stayed. This is accomplished by the staybolts S, S. The

flat top of the fire-box is strengthened by a series of parallel girders *P*, *P*. As an additional security, the girders are sometimes attached to the shell by the "sling-stays" *R*, *R*.

The gases of combustion pass directly from the furnace through the tubes *T*, *T*, to the smokebox *B*, and out of the stack *C*. In railway locomotives, a strong draft is obtained by allowing the exhaust steam to discharge through the smokestack. The escaping steam carries along the air and the escaping gases in the smokebox *B*, thereby drawing a new supply of gases through the tubes *T*, *T*, and a supply of air through the grate.

The tubes of the locomotive boiler are about 12 feet long, two inches in diameter, and made of iron or steel. The tubes of stationary and portable boilers of this type are generally of larger diameter, as there is less demand for great quantities of steam. The locomotive type of boiler is **self-contained**; that is, it requires no brickwork for flues or for setting.

2025. The Return-Tubular Boiler.—This type of boiler is a development of the flue-boiler, the two large flues of the latter being replaced by a large number of small

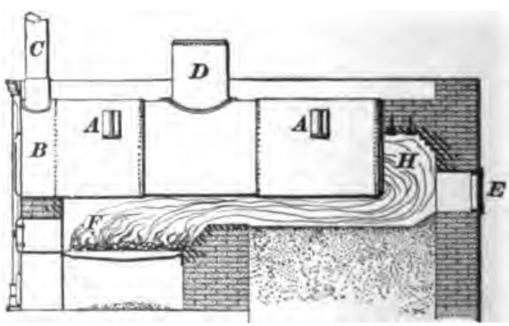


FIG. 660.

tubes. The object of introducing the numerous tubes is to increase the heating surface of the boiler.

A side view of a tubular boiler is shown in Fig. 660; a cross-section through the tubes is shown in Fig. 661. The

tubes extend the whole length of the shell; the ends are beaded into holes in the heads of the boiler. The front end of the shell projects beyond the head, forming the smokebox *B*, into which opens the stack *C*.

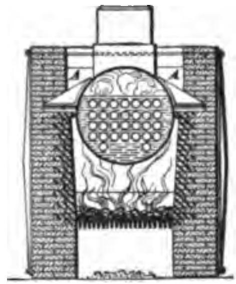


FIG. 661.

The shell is suspended on the side walls by the brackets *A*, *A*, which are riveted to the shell. The boiler is usually provided with a dome *D*, though this is sometimes left off. The walls are built and supported by buckstaves in practically the same manner as those previously described. Since this type of boiler is generally short, one bridge only is used. Firebrick is used for all parts of the wall exposed to the fire or heated gases. The fittings are not shown in the figure. The safety-valve would be placed on top of the dome, and the pressure-gauge and gauge-cocks would be placed on the front. The manhole is either in one of the heads or on top of the shell. The feed-pipe may enter the front head or the top, while the blow-off pipe is placed at the bottom of the shell, at the rear end. Access is given to the rear end of the boiler through the door *E*.

As usual, the furnace *F* is placed under the front end of the boiler. The gases pass over the bridge, along under the boiler into the chamber *H*, then back through the tubes to the smokebox *B*, and out of the stack *C*.

The return-tubular boiler is probably more used in the United States than any other. The details of its construction and setting will be shown later.

2026. The Vertical Boiler.—This type is essentially a modification of the locomotive type placed on end. A common form of vertical boiler is shown in Fig. 662. It consists of a vertical cylindrical shell, in the lower end of which is placed a fire-box *F*. The lower rim of the fire-box and the lower end of the shell are separated by a wrought-iron ring *k*, to which both are riveted, the rivets going through

both plates and ring. The shell and fire-box are also stayed together by the staybolts *a*, *a*. The space between the two is filled with water, so that the fire-box is nearly surrounded by it. The boiler-shell, and likewise the grate *E*, rest upon a cast-iron base *D* which forms the ash-pit. A series of vertical tubes *t*, *t* extend from the top sheet of the fire-box to the upper head of the shell. The tubes serve as stay-rods and strengthen the flat surfaces which they connect. The upper ends of the tubes open directly into the chimney or smokestack *K*. The gases from the furnace thus pass directly through the tubes and out of the stack.

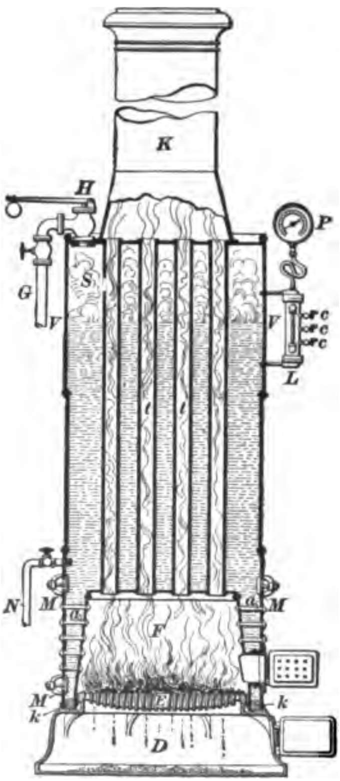


FIG. 662.

The safety-valve is shown at *H*, with the main steam-pipe *G* leading from it. The pressure-gauge *P* and gauge-cocks *c*, *c*, *c* are attached to a column *L*, which communicates in the usual manner with the interior of the shell. The construction of this type of boiler does not generally permit the use of manholes, but handholes *M*, *M* are placed in convenient positions for cleaning out mud and sediment.

The boiler is fed through the feed-pipe *N*, which is connected to a pump or injector.

When the tubes extend through to the upper head of the boiler, as shown in Fig. 662, their upper ends pass through the steam-space *S* above the water-line *V V*. This is considered to be a bad feature, since the tubes are liable to

become overheated and to collapse, when the boiler is subject to rapid firing.

In the form of vertical boiler shown in Fig. 663, this danger is avoided. A chamber or smokebox *I* extends down from the upper head of the shell so that its bottom plate is always below the water-line. The upper ends of the tubes *t*, *t* are expanded into the lower plate of this chamber, and, therefore, the tubes are always surrounded by water from end to end. A vertical boiler constructed in this manner is said to have a *submerged head*. Aside from the submerged head, the construction of the boiler of Fig. 663 is similar to that of Fig. 662.

Vertical boilers are generally wasteful of fuel; they are, however, self-contained, require but little floor space, and are easy to construct and repair. For these reasons, the vertical type of boiler is very popular with a large class of steam-users.

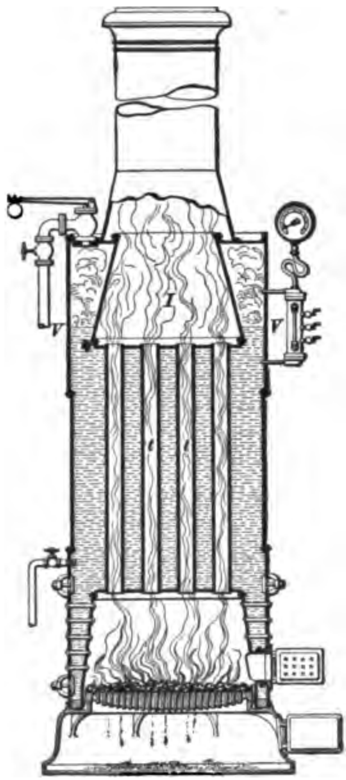


FIG. 663.

WATER-TUBE BOILERS.

2027. The **Babcock and Wilcox water-tube boiler** is shown in Fig. 664. It consists essentially of a main horizontal drum *B* and of a series of inclined tubes *T*, *T*. (Only a single vertical row of tubes is shown by the figure, but it will be understood that each nest of tubes is composed of several vertical rows.) There are usually 7 or 8 of these vertical rows to each horizontal drum. The front ends of the tubes of a vertical row are all expanded into a hollow iron

casting H called a **header.** The rear ends are expanded into a similar header, and the front and rear headers are placed in communication with the drum by tubes, or *risers*, C and C', respectively. In front of each tube, a handhole is placed in the header for the purpose of cleaning, inspecting, or removing the tubes.

The method of supporting the boiler is not shown in the figure. The usual method is to hang the boiler from wrought-iron girders resting on vertical iron columns. The

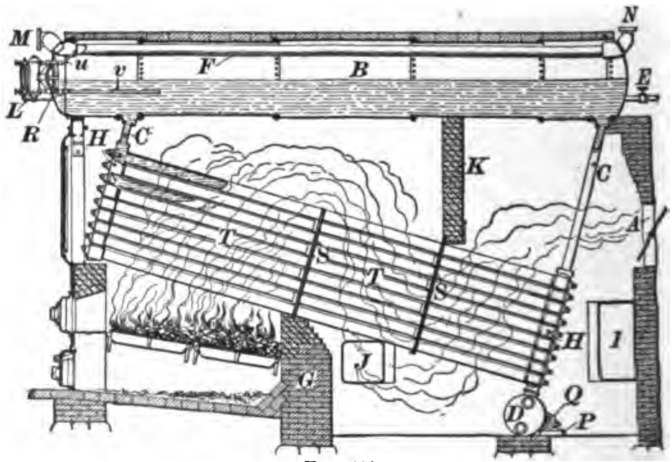


FIG. 664.

brickwork setting is not depended upon as a means of support. This make of boiler, in common with all others of the water-tube type, requires a brickwork setting to confine the furnace gases to their proper field.

The furnace is of the usual form, and is placed under the front end of the nest of tubes. The bridge-wall G is built in contact with the tubes; another firebrick wall K is built between the tubes and drum. These walls and the baffle-plates S, S force the hot furnace gases to follow a zigzag path back and forth through the tubes. The gases finally pass through the opening A in the rear of the wall, into the chimney-flue.

The feed-water is introduced through the feed-pipe E. The steam is collected in the dry-pipe F, which terminates

in the nozzles *M* and *N*, to one of which is attached the main steam-pipe, and to the other the safety-valve.

The pressure-gauge, cocks, etc., are attached to the column, which communicates with the interior of the shell by the small pipes *u* and *v*, the former of which extends into the dry-pipe, the latter into the water.

At the bottom of the rear row of headers is placed the mud-drum *D*. Since this drum is the lowest point of the water-space, most of the sediment naturally collects there. This sediment may be blown out from time to time through the blow-out pipe *P*. The drum *D* is provided with a hand-hole *Q*, and a manhole *R* is placed in the front head of the drum *B*. The heads of the drums are of hemispherical form, and, therefore, do not require bracing. Access may be had to the space within the walls through the doors *I* and *J*.

The circulation of water takes place as follows: The cold water is introduced into the rear of the boiler; the furnace being under the higher end of the tubes, the water in that end expands upon being heated, and is also partially changed to steam; hence, a column of mingled water and steam rises through the front headers to the front end of the drum *B*, where the steam escapes from the surface of the water. In the meantime, the cold water fed into the rear of the drum descends to the rear headers through the tubes *C*, to take the place of the water which has risen in front. Thus, there is a continuous circulation in one direction, sweeping the steam to the surface as fast as it is formed, and supplying its place with cold water. Most of the sediment sinks to the mud-drum *D*, from which it is blown out from time to time.

2028. The **Heine water-tube boiler** is shown in **Fig.** 665. It differs in many respects from those already described. It consists of a large main drum *A*, which is above and parallel with the nest of tubes *T*, *T*. Both drum and tubes are inclined at a small angle with the horizontal, so that the water-level is about $\frac{1}{3}$ the height of the drum in front and about $\frac{2}{3}$ the height in the rear. The ends of the

tubes are expanded into the large wrought-iron water-legs *B*, *B*. These legs are flanged and riveted to the shell. The shell is cut out for about $\frac{1}{4}$ the circumference to receive the water-legs, the opening being from 60 to 90 per cent. of the cross-sectional area of the tubes. The drum-heads are of a hemispherical form, and, therefore, do not need bracing.

The water-legs form the natural support of the boiler.

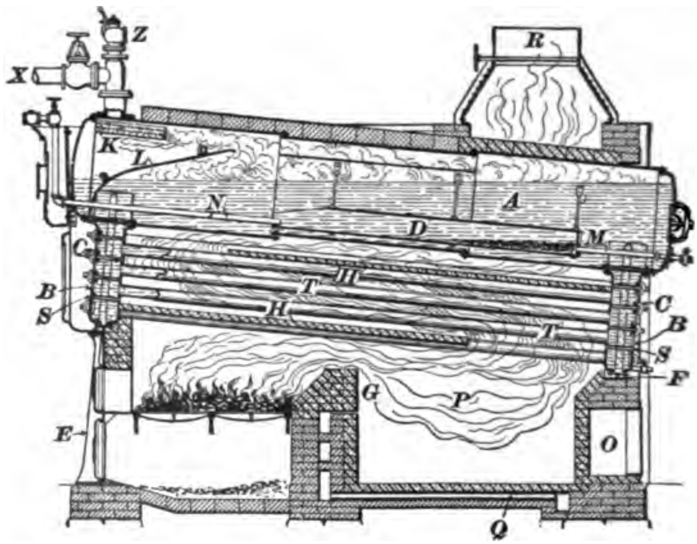


FIG. 665.

The front water-leg is placed on a pair of cast-iron columns *E* which form part of the front of the boiler. The rear water-leg rests on rollers (shown at *F*) which may move freely on a cast-iron plate bedded in the rear wall. The rollers allow the boiler to expand when heated.

The boiler is enclosed by a brickwork setting in the usual manner. The bridge *G* is made largely of firebrick. It is made hollow, and has openings in the rear to allow air to pass into the chamber *P* and mix with the furnace gases. The air is drawn from the outside through the channel *Q* in the side wall. The air is, of course, heated in passing through the bridge. In the rear wall is the arched opening *O*, which is

closed by a door, and further protected by a thin wall of firebrick. When it is necessary to enter the chamber *P*, the wall may be removed and afterwards replaced.

The feed-water is brought in through the feed-pipe *N*, which passes through the front head. As the water enters, it flows into the mud-drum *D*, which is suspended in the main drum below the water-line, and is thus completely submerged in the hottest water in the boiler. This high temperature is useful in precipitating the impurities contained in the feed-water. These impurities settle in the mud-drum *D*, and may then be blown out through the blow-out pipe *M*.

Layers of firebrick *H*, *H* are laid at intervals along the rows of tubes, which act as baffle-plates, and force the furnace gases to pass back and forth through the tubes. The gases finally escape through the chimney *R* placed above the rear end of the boiler. To protect the steam-spaces of the drum from the action of the hot gases, the drum in the vicinity of the chimney is protected by firebrick, as shown in the figure.

The steam is collected and freed from water by the perforated dry-pipe *K*. The main steam-pipe with its stop-valve is shown at *X*, the safety-valve at *Z*. In order to prevent a combined spray of mixed water and steam from spurting up from the front header and entering the dry-pipe, a deflecting plate *L* is placed in the front end of the drum.

A manhole *Y* is placed in the rear head of the drum. The flat sides of the water-legs, which are made hollow to give access to the outside of the tubes, are stayed together by the staybolts *S*, *S*. In front of each tube, a handhole *C* is placed to give access to the interior of the tubes.

Where a battery of several of these boilers is used, an additional steam-drum is placed above and at right angles to the drums *A*, *A*.

2029. The **Stirling boiler,** shown in Fig. 666, is a departure from the regular type of water-tube boilers. It consists of a lower drum *A*, connected with three upper

drums B, B, B by three sets of nearly vertical tubes. These upper drums are in communication through the curved tubes C, C, C. The curved forms of the different sets of tubes allow the different parts of the boiler to expand and contract freely without strain.

The boiler is enclosed in a brickwork setting, as shown.

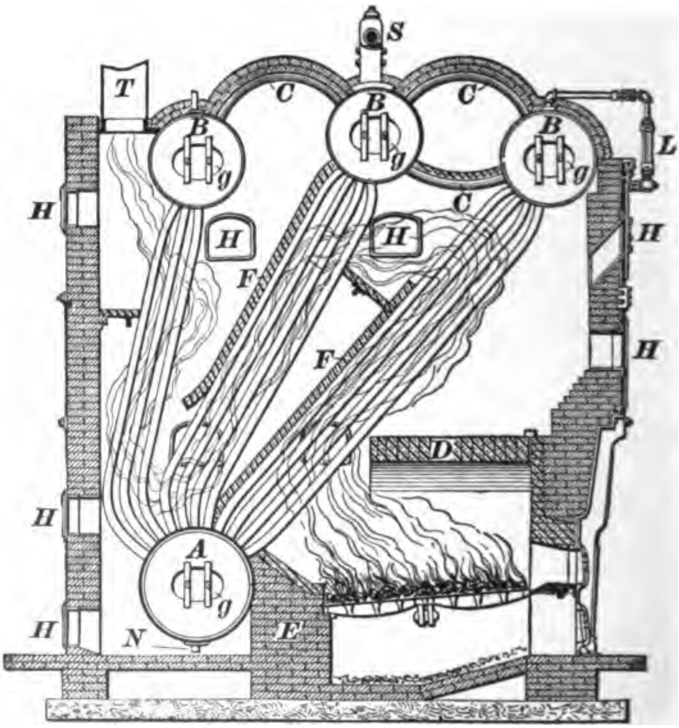


FIG. 666.

The setting is built with various holes H, H, so that the interior may be inspected or repaired.

The boiler is suspended from a framework of wrought-iron girders, not shown in the figure.

The bridge E is lined with firebrick, and is built in contact with the lower drum A and the front nest of vertical tubes. An arch D is built above the furnace, and this, in

connection with the bafflers F, F, directs the course of the heated gases, causing them to pass up and down through the tubes. The arch and bafflers are made of firebrick.

The cold feed-water enters the rear upper drum and descends through the rear nest of tubes to the drum A, which acts as a mud-drum, and collects the sediment brought in by the water. A blow-off pipe N permits the removal of the sediment. The steam collects in the upper drums B, B. To the middle drum is attached the steam-pipe and safety-valve S.

The chimney T is located behind the rear upper drum. Therefore, the cold feed-water enters the coolest part of the boiler, and the circulation of the water is directly opposite to that of the escaping hot gases.

The water-column L with its fittings is placed in communication with the front upper drum. All the drums are provided with large manholes g.

The boiler is made with a cast-iron front.

2030. The following advantages are claimed for the Stirling boiler:

(1) The vertical position of the tubes prevents the collection of sediment, and at the same time encourages the rapid rise and separation of the steam as soon as it is formed. (2) The boiler is very simple and easy to construct; there are no flat surfaces to be stayed, and there is little or no machine work required in its manufacture. (3) It is very accessible for cleaning or repairs; any part of the boiler may be inspected by removing the four manhole plates g.

The various water-tube boilers just described are coming into extensive use. The most important points in their favor are their safety from disastrous explosion and their economy in the use of fuel. An objection sometimes urged against water-tube boilers is that they require more attention; since they usually have much less cubic capacity than cylindrical boilers of the same power, the water-level must be closely watched.

STRENGTH OF BOILERS.

2031. Steam-boilers can be designed and constructed to safely generate and operate under almost any desired steam pressure, however great it may be. The common practice among engineers, however, is rarely, if ever, to go above 250 pounds per square inch, and in the majority of plants throughout the country the steam pressure does not exceed 60 pounds per square inch.

2032. In approximately determining the safe working pressure under which any well-designed boiler may be operated, it is only necessary to find the diameter of the largest cylindrical shell used in its construction, and the thickness of the plate of which the shell is made. Then the safe working pressure may be found by the following rule:

Rule.—*Multiply the thickness of the plate in inches by the constant given below, and divide the product by the diameter of the shell in inches; the quotient will be the allowable gauge pressure.*

Let p = safe working pressure;
t = thickness of plate in inches;
d = diameter of shell in inches;
c = constant.

Then, $$p = \frac{c\,t}{d}. \qquad \textbf{(141.)}$$

The following constants are to be used in formula **141**:

Wrought-iron plate, single-riveted joint	10,224
Wrought-iron plate, double-riveted joint	13,152
Steel plate, single-riveted joint	16,608
Steel plate, double-riveted joint	20,688

Example.—If a return-tubular boiler is made of $\frac{5}{16}$ of an inch thick wrought-iron boiler plate, double riveted, and is 5 feet in diameter, what is the greatest steam pressure under which such a boiler can be safely operated?

Solution.—Applying formula **141**,

$$p = \frac{13,152 \times \frac{5}{16}}{60} = 68.5 \text{ pounds per square inch, gauge. Ans.}$$

$68.5 + 14.7 = 83.2$ pounds per square inch above a vacuum.

HORSEPOWER OF BOILERS.

2033. The **horsepower** of a boiler is a measure of its capacity for generating steam. Boiler-makers usually rate the horsepower of their boilers as a certain fraction of the heating surface; but this is a very indefinite method, for with the same heating surface, different boilers of the same type may, under different circumstances, generate different quantities of steam.

In order to have an accurate standard of boiler-power, the American Society of Mechanical Engineers has adopted as a standard horsepower *an evaporation of 30 pounds of water per hour from a feed-water temperature of 100° F. into steam at 70 pounds gauge pressure*, which is considered equivalent to 34.5 units of evaporation; that is, to 34.5 pounds of water evaporated from a feed-water temperature of 212° F. into steam at the same temperature.

EXAMPLE.—A boiler evaporates per hour 1,980 pounds of water from a feed temperature of 100° into steam at 70 pounds gauge pressure. What is the horsepower of the boiler?

SOLUTION.—Since, under the given conditions, an evaporation of 30 pounds is equivalent to one horsepower, the number of horsepower is $1,980 \div 30 = 66$. Ans.

2034. In the various types of boilers there is a nearly constant ratio between the water-heating surface and the horsepower, and also between the heating surface and the grate area. These ratios are given in the following table:

TABLE 43.

RATIO OF HEATING SURFACE TO HORSEPOWER AND OF HEATING SURFACE TO GRATE AREA.

Type of Boiler.	Ratio $= \frac{\text{Heating Surface}}{\text{Horsepower}}$	Ratio $= \frac{\text{Heating Surface}}{\text{Grate Area}}$
Plain Cylindrical	6 to 10	12 to 15
Flue	8 to 12	20 to 25
Return-Tubular.	14 to 18	25 to 35
Vertical	15 to 20	25 to 30
Water-Tube	10 to 12	35 to 40
Locomotive	1 to 2	50 to 100

If the heating surface of a boiler is known, the horsepower can be found roughly; thus, if a return-tubular boiler has a heating surface of 900 square feet, its horsepower lies between $\frac{900}{18} = 50$ H. P. and $\frac{900}{14} = 64.3$ H. P., say about 57 H. P.

2035. The *heating surface* of a boiler is the portion of the surface exposed to the action of flames and hot gases. This includes, in the case of the multitubular boiler, the portions of the shell below the line of brickwork, the exposed heads of the shell, and the interior surface of the tubes. In the case of a water-tube boiler, the heating surface comprises the portion of the shell below the brickwork, the outer surface of the headers, and outer surface of tubes. In any given case, the heating surface may be calculated by the rules of mensuration. The following example will show the method of calculating the heating surface of a return-tubular boiler:

EXAMPLE.—A horizontal return-tubular boiler has the following dimensions: Diameter, 60 inches; length of tubes, 12 feet; internal diameter of tubes, 3 inches; number of tubes, 82. Assume that $\frac{2}{3}$ of the shell is in contact with hot gases or flame and $\frac{2}{3}$ of the two heads are heating surface.

SOLUTION.—
Circumference of shell $= 60 \times 3.1416 = 188.496 = 188.5$ in., say.
Length of shell $= 12 \times 12 = 144$ in.
Heating surface of shell $= 188.5 \times 144 \times \frac{2}{3} = 18{,}096$ sq. in.
Circumference of tube $= 3 \times 3.1416 = 9.425$ in., nearly.
Heating surface of tubes $= 82 \times 144 \times 9.425 = 111{,}290.4$ sq. in.
Area of one head $= 60^2 \times .7854 = 2{,}827.44$ sq. in.
Two-thirds area of both heads $= \frac{2}{3} \times 2 \times 2{,}827.44 = 3{,}769.92$ sq. in.
From the heads must be subtracted twice the area cut out by the tubes; this is $82 \times 3^2 \times .7854 \times 2 = 1{,}159.26$.
Total heating surface in square feet =

$$\frac{18{,}096 + 111{,}290.4 + 3{,}769.92 - 1{,}159.26}{144} = 916.64 \text{ sq. ft. Ans.}$$

CHIMNEYS.

2036. Chimneys have two important duties to perform, the first being to carry off the waste furnace gases, which requires size, and the second, to produce a draft sufficient to insure the complete combustion of the fuel, which requires

height. The area of a chimney is usually made from one-seventh to one-tenth as large as the area of the furnace-grates, or of about the same cross-section as the cross-sectional area of the flues or tubes; we have, therefore, a comparatively simple method of determining one of the required dimensions of a chimney, and, when this is known, it becomes an easy matter to determine the height of the chimney when the horsepower of the boiler has been ascertained.

The horsepower of a boiler being given and the necessary chimney area having been determined, the following rule gives the required height that the chimney must be to produce the necessary draft :

Rule.—*From 3.33 times the area of the chimney in square feet, subtract twice the square root of the area of the chimney in square feet, and divide the given horsepower by the remainder. The square of the quotient will be the height of the chimney in feet.*

Let A = area of chimney;
H = horsepower of boiler;
h = height of chimney.

Then, $$h = \left(\frac{H}{3.33\,A - 2\sqrt{A}}\right)^2. \qquad \textbf{(142.)}$$

EXAMPLE.—What must be the height of a chimney which is to have a cross-sectional area of 7 square feet, and to supply the draft for a 141 horsepower boiler?

SOLUTION.—Using formula **142**,

$$h = \left(\frac{141}{3.33 \times 7 - 2\sqrt{7}}\right)^2 = \left(\frac{141}{3.33 \times 7 - (2 \times 2.65)}\right)^2 = 61.3 \text{ feet. Ans.}$$

STEAM-ENGINES.

THE PLAIN SLIDE-VALVE ENGINE.

GENERAL DESCRIPTION.

2037. The **plain slide-valve engine** is the most simple of all of the many forms of steam-engines now in use. In its construction and operation, however, all of the fundamental principles of this class of machinery are involved.

2038. In Fig. 667 such an engine is shown, and in Fig. 668 is shown an enlarged section of a steam-cylinder. Referring to these figures, *H* is the head end and *C* the crank end of the steam-cylinder; *B* and *B'* are the steam-ports; *D* is the steam-chest; *E* is the exhaust-port; *N* and *N'* are the cylinder-heads; *S* is the steam supply-pipe; *O* is the exhaust-pipe, and connects with the exhaust-port *E*; *G* is one of the two guide-bars (the other, which is not designated, is on the opposite side of the cross-head *2*); *R* and *R'* are the shaft-bearings, and *T* is the bed or frame of the engine. The above are all stationary parts of the engine, or parts which do not change their relative positions when the engine is in motion. *P* is the piston; *1* is the piston-rod; *2* is the cross-head; *3* is the cross-head pin; *4* is the connecting-rod; *5* is the crank; *6* is the crank-pin; *7* is the crank-shaft; *8* is the fly-wheel; *9* is the eccentric; *10* is the eccentric-strap; *11* is the eccentric-rod; *12* is the rocker; *13* is the valve-rod, or stem, and *V* is the slide-valve. These are all movable parts of the engine, or parts which change their relative positions when the engine is in motion.

2039. The stroke of the engine is equal to the throw of the crank, or to the diameter of the circle described by the

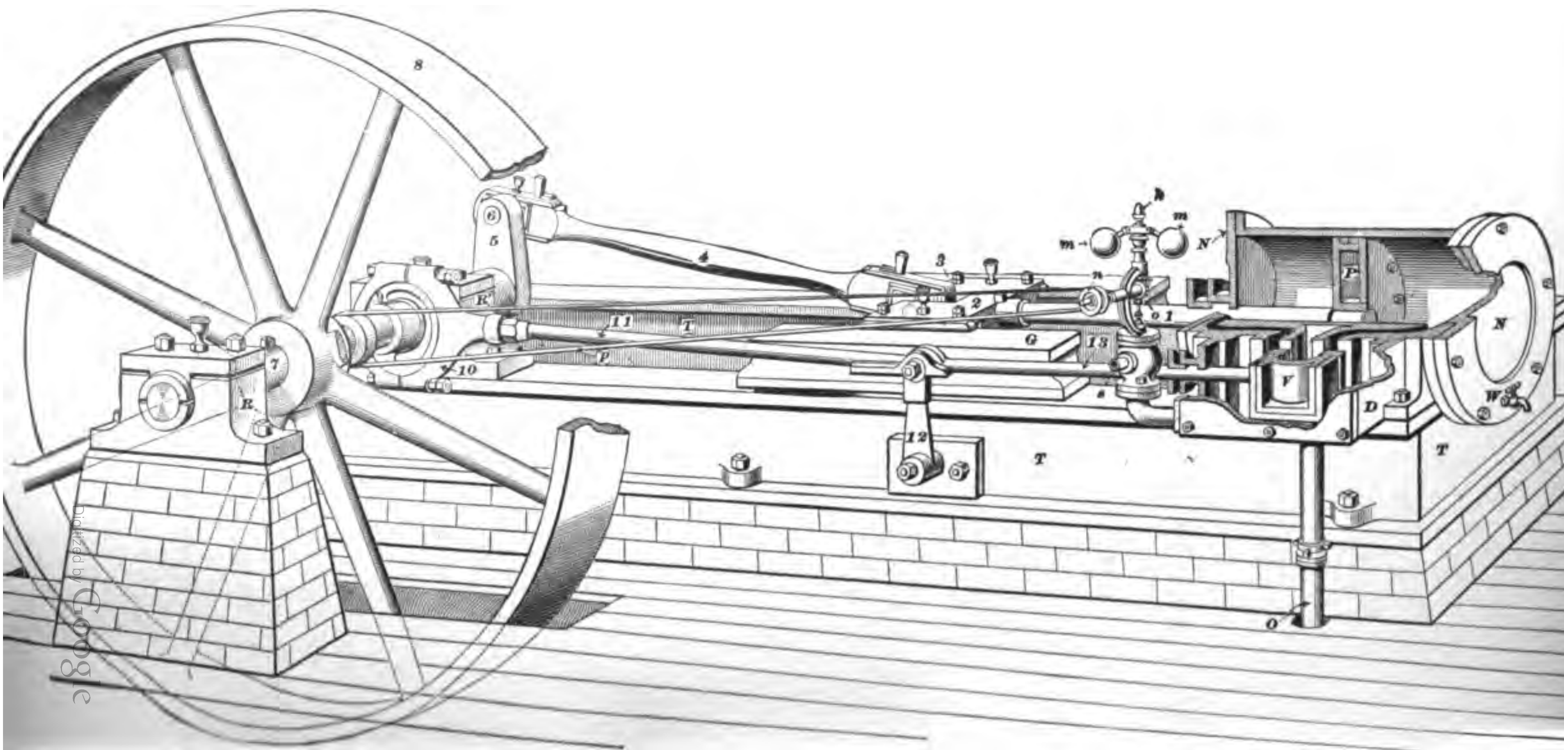


FIG. 907.

center of the crank-pin *6*. It is also equal to the cross-head or piston travel, or the distance through which the cross-head or piston moves, and it determines the working length *W* of the cylinder, as shown in Fig. 668. The bore of the cylinder is *M*, Fig. 668. The counter-bores *F* and *F'* are enlargements, into which the piston projects at the end of each stroke. They prevent the formation of shoulders at the ends of the cylinder by insuring an equal wear of the cylinder over its entire working length. Such shoulders would cause a pounding of the piston when the length of the

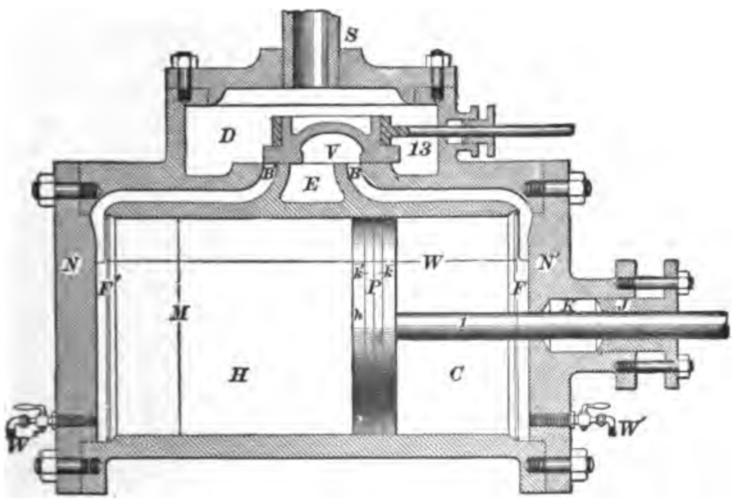


FIG. 668.

connecting-rod is increased by the taking up of the wear of its joints. The clearance at one end of the cylinder is the volume that remains when the piston has completed its stroke—it includes the steam-port. It is diminished at the crank end by the volume of that portion of the piston-rod remaining within the cylinder. The volume of the cylinder is equal to the volume of the clearance at one end plus the volume swept through during one stroke of the piston. It is less at the crank end by an amount equal to the volume of that portion of the piston-rod remaining in the cylinder.

Drain-valves W' and W'' are fitted in each end of the cylinder through which any condensed steam may be discharged.

The piston is given a loose fit in the cylinder, and has split rings *k* and *k'* inserted, which spring out so as to press against the wall of the cylinder, and prevent leakage of steam between the wall of the cylinder and piston. Pistons are usually supplied with a follower-plate *h*, which is bolted to the head end of the piston *P*, in order to hold these split rings *k* and *k'* in place. The piston-rod *1* is a perfectly round, smooth bar, rigidly connected to both the piston *P* and the cross-head *2*.

K is a stuffing-box in which packing is placed, and is fitted with a gland *J*, which, when bolted down, compresses the packing around the piston-rod *1*, and makes a steam-tight joint. This packing is usually made in the form of split rings, which are so placed that the split of the first ring is covered by the solid part of the next ring. When repacking, care should be taken not to cause unnecessary friction by too much pressure from the gland. The cross-head *2* is given an easy sliding fit between the guide-bars, which are in line with the path of the piston-rod, and combine with the cross-head to relieve the piston-rod of all bending strains.

2040. The connecting-rod *4* forms the connecting-link between the cross-head and crank *5*. The joint between the cross-head *2* and connecting-rod *4* is made by the cross-head pin *3*, and that between the connecting-rod and crank by the crank-pin *6*. Connecting-rods are usually made from 2 to 3 times the length of the stroke, or from 4 to 6 times the length of the crank, or from 4 to 6 "cranks" in length, as it is called.

The crank-shaft *7* forms a rigid connection between the crank *5*, the eccentric *9*, and the fly-wheel *8*. The power developed in the engine is, therefore, transmitted through the shaft. When the engine is running, all the energy which has been expended in giving the fly-wheel its speed is stored up in the fly-wheel. This energy, from the law of

the conservation of energy, is utilized in assisting the steam-power in overcoming any sudden change in the load on the engine, as well as in carrying the crank over its dead-center positions. These occur twice in every revolution of the crank—when the piston reaches the end of its stroke, and the centers of the cross-head pin *3*, crank-pin *6*, and crank-shaft *7* all lie in the same straight line.

2041. The eccentric *9*, which imparts motion to the slide-valve *V*, is the exact equivalent of a crank having the same throw. This is clearly shown in Fig. 669, in which *9*

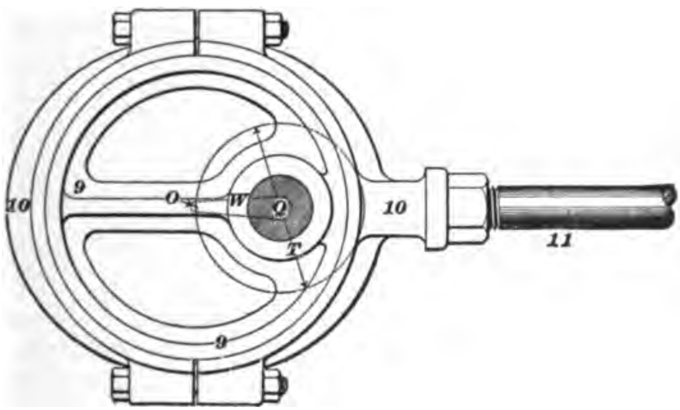


FIG. 669.

is the eccentric, *10* is its strap, *11* is the eccentric-rod, and *W* is a crank having a throw *T*, equal to that of the eccentric. The center of the crank-shaft *Q* is the center of rotary motion. The dotted circle represents the path of the common center *O* of the eccentric and crank *W*. The eccentric revolves freely in the eccentric-strap *10*, which is rigidly connected to the eccentric-rod *11*. (See Figs. 667 and 669.) In practice, the diameter of the shaft generally exceeds the throw of the eccentric. In plain slide-valve engines the eccentric is usually keyed to the shaft after being properly adjusted. The connection between the eccentric-rod *11*, Fig. 667, and the valve-rod or stem *13*

varies slightly in different engines of this class. The illustration exhibits a common form called the rocker connection.

THE PLAIN SLIDE-VALVE.

ACTION OF THE SLIDE-VALVE.

2042. In the discussions which follow, it must be remembered that the steam enters the steam-chest as it comes from the boiler through the steam-pipe S (Figs. 667 and 668), and is called live steam; that, while it is within the cylinder of the engine, the heat stored in the steam is the active agent in the accomplishment of the results there obtained, and that all the steam discharged from the cylinder passes out of the exhaust-pipe O, Fig. 667, through the exhaust-port E, Fig. 668. It must also be understood that the motion of the *piston* is imparted to the *crank*, and that the *slide-valve* receives its motion from the *eccentric*. The crank and the eccentric have the same rotary motion, in consequence of the rigid shaft connection between them. The angle between the center lines of the crank and the eccentric is always a little more than a right angle.

2043. In order to show the action of the slide-valve, a series of skeleton diagrams, Figs. 670 to 672, have been drawn.

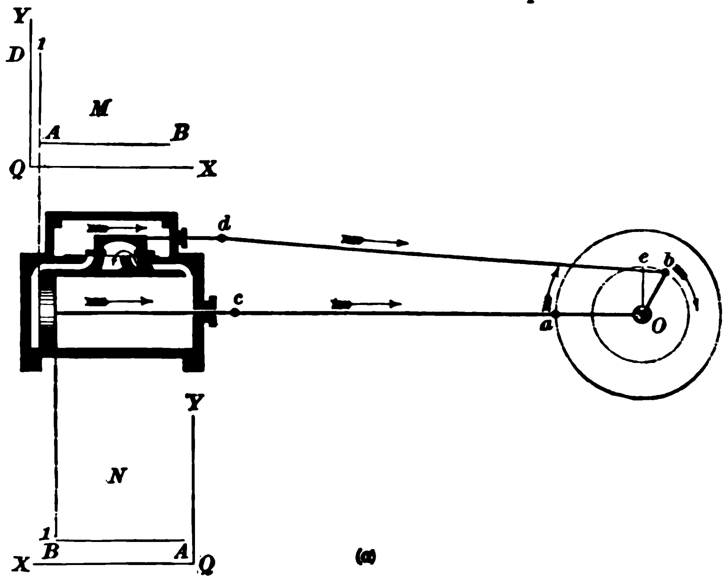
These diagrams have been distorted, in order that the eccentric radius might be long enough to show up well; it is three times as long as it should be for the amount of valve movement shown by the figure. The diameter of the crank circle is also a little greater than the stroke of the piston for the same reason. In order to show the distribution of steam by the valve, a diagram has been drawn above and below each cylinder, those above being marked M, and those below, N. These diagrams are supposed to be drawn in the following manner: Imagine it to be possible to connect two small pipes to the piston, one on each side. Suppose each pipe has a steam-tight piston working in it, the lower side of the pistons being subjected to the steam pressure in the cylinder, and the upper side to the atmospheric

pressure. Suppose, further, that there is a coiled spring on top of the piston; that a piston-rod passes through the center of the spring, and that a pencil is attached to the end of the piston-rod. If a pressure of 10 pounds is required to compress the spring 1 inch, it is evident that for every 10 pounds pressure in the cylinder, the pencil will move upwards 1 inch, and, if it touched a sheet of paper, would mark a line on that paper. It will now be presumed that an arrangement like that just described is attached to the steam-engine piston, and that the pencil touches a sheet of paper, which is held stationary. Then, when the steam-piston moves ahead, the pencil will make straight lines at heights corresponding to the steam-pressure on the under sides of the little pistons, except when the pressure of the steam in cylinder varies, in which case the pencil will move up or down, according as the pressure increases or diminishes.

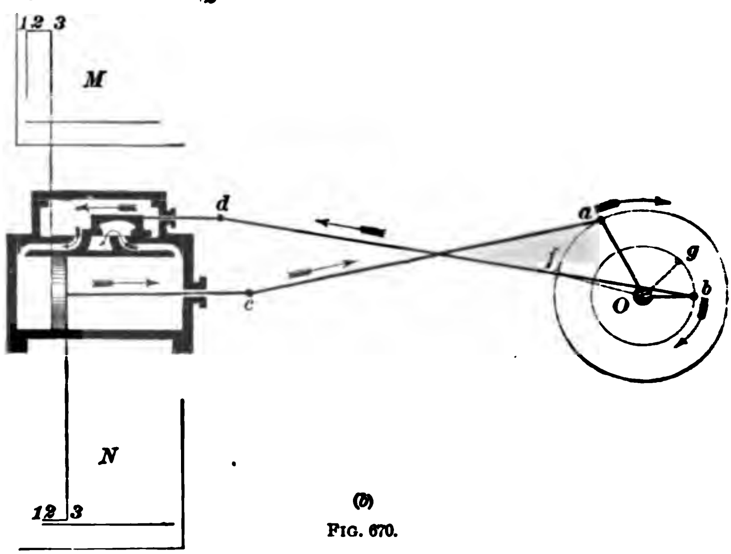
Having made these suppositions clear, let *Q X*, Figs. 670 to 672, represent the line which the pencil would trace if there were a perfect vacuum in the cylinder; i. e., *Q X* is the line of zero pressure, or the **vacuum line;** also let *A B* represent the **atmospheric line,** or the line which the pencil would trace if the pressure in the cylinder was just equal to that of the atmosphere, and *Q Y* the line of no volume. Then, the point *Q* represents no volume and no pressure. Finally, let *1 D* represent the volume of the clearance; that is, the space between the piston and cylinder-head when the piston is at the end of its stroke.

2044. Consider Fig. 670 (*a*). The piston is represented as just beginning the forward stroke, and the valve as just commencing to open the left steam-port, both moving in the same direction, as shown by the arrows. If the valve had no outside lap (see Art. **2047**), the position of the eccentric center would be at *e*, but on account of the lap, the valve has moved ahead of its central position in order to bring its edge to the edge of the port. To accomplish this, the eccentric center has been moved from *e* to *b*, *O b* being the position of the eccentric radius. The angle *b O e*,

which the eccentric radius makes with the position it would



(a)



(b)

FIG. 670.

be in if there were no lap or lead, is called the **angle of advance.**

Assume that the piston and valve have moved a very small distance, just sufficient to admit steam to fill the clearance-space on the left of the piston, so that the steam acts on the piston at full boiler-pressure. If the length of the line *A 1* represents the boiler-pressure (gauge), the pencil which registers the pressure on the left side of the piston will be at *1*. The steam on the right side of the piston is flowing (*exhausting*) into the atmosphere through the exhaust-port, as shown by the arrow. As the size of the exhaust-port is limited by practical considerations, the exhaust is not perfectly free, and there is a slight pressure on the exhaust side of the piston, in addition to the atmospheric pressure. This is termed **back-pressure.** Therefore, in the diagram *N*, let *1* be the position of the second pencil; then, *1 B* is the back-pressure.

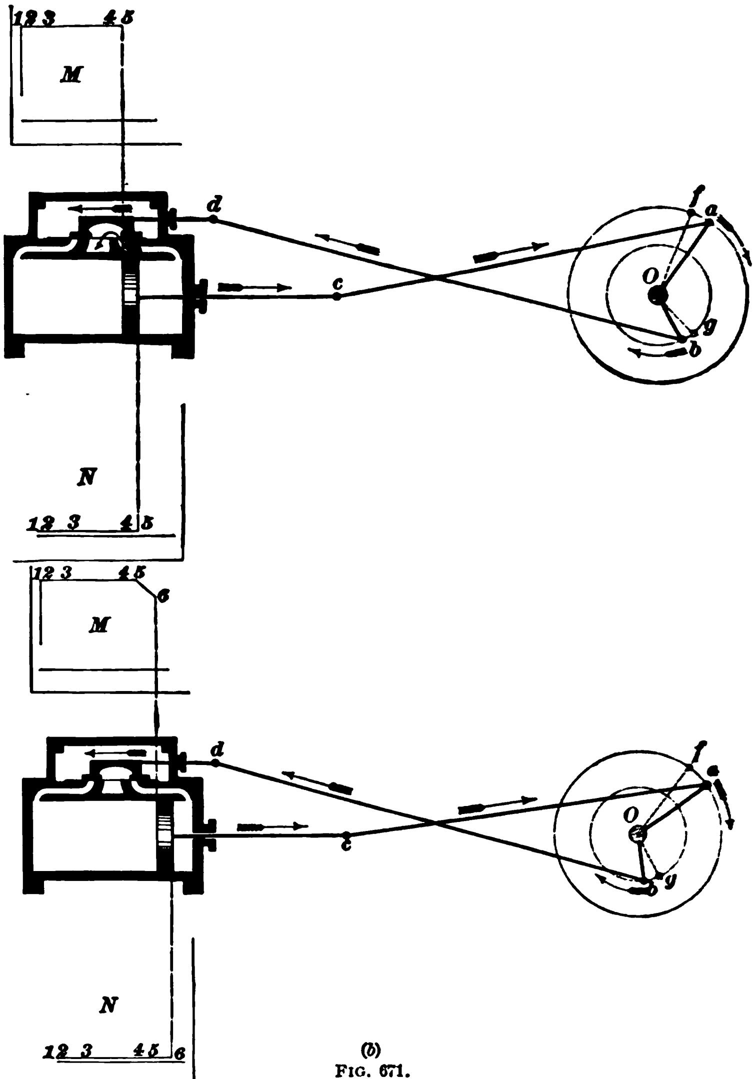
In Fig. 670 (*b*) the piston has advanced far enough to enable the valve to reach the end of its stroke and open the port its full width. The crank and eccentric have moved to the positions *O a* and *O b*. The eccentric radius is horizontal, and any further movement of the crank will cause the eccentric to travel in the lower half of its circle and make the valve move back. In the diagrams *M* and *N*, the pencil has traced the lines *1–3*.

Fig. 671 (*a*) marks one of the most important points of the stroke. Here the valve has closed the steam-port, i. e., *cut off* the steam, and from here to the end of the stroke, the steam in the cylinder expands. This point of the stroke is called the **point of cut-off.**

The exhaust-port is now partially closed. The crank and eccentric have moved to the positions indicated. During this movement, the pencils have traced the lines *3–5*.

Fig. 671 (*b*) shows another very important valve position. Here the inside edge of the valve closes the exhaust-port, and, from now on to the end of the stroke, the steam in front of the piston is compressed. This point of the stroke is called the **point of compression.** In the diagrams *M* and *N*, the lines *5–6* are traced by the pencils. The line *5–6* on the diagram *M* is an expansion line, the pressure falling

as the piston moves ahead. This period during which the pressure falls is called the **period of expansion.**



(b)
Fig. 671.

In Fig. 672 (*a*) the piston has advanced far enough to cause the left inside edge of the valve to be in line with the

inside edge of the left port. The slightest movement of

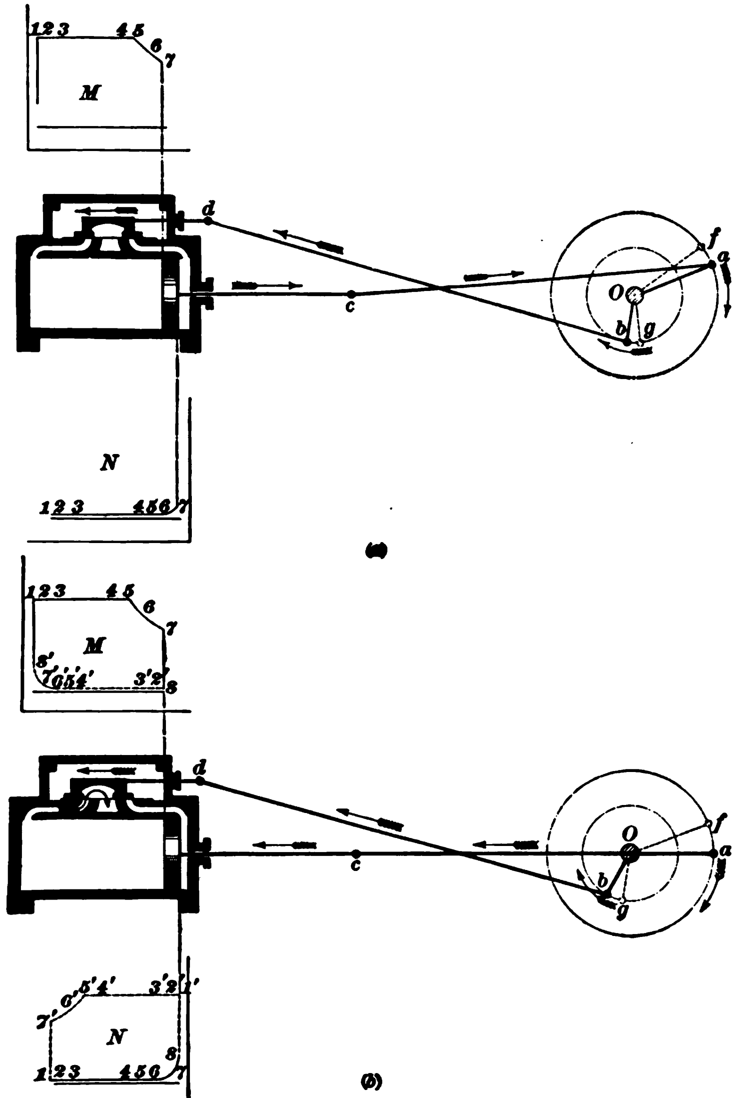


FIG. 672.

the valve to the left will open the left port to exhaust. This point of the stroke is called the **point of release**

Expansion really ends here, although, on account of the limitation in the size of the ports, there will still be a slight further expansion, owing to the inability of the steam to escape instantly. During this last movement of the piston, the pencils trace the lines *6–7* on the diagrams *M* and *N*. On the diagram *M*, the line *6–7* is a continuation of the expansion line *5–6*, while in the diagram *N* it shows part of the compression line, the pressure rapidly increasing as the piston nears the end of the stroke.

In Fig. 672 (*b*) the piston has reached the end of its forward stroke, and is about to begin the return stroke. The right outside edge of the valve is in line with the outside edge of the right port. The steam is exhausting from the head end of the cylinder, as shown by the arrows. The crank and eccentric are both diametrically opposite their positions in Fig. 670 (*a*). In the diagrams *M* and *N*, the pencils have traced the lines *7–8*. *M* shows that the pressure has fallen very rapidly from *7* to *8*, while in *N* it has risen from *7* to *8*. The very slightest movement of the piston to the left will admit steam to the crank end of the cylinder and cause the pencil to rise to the point *1'*.

During the return stroke, the above-described actions of the steam will be repeated, the pencils tracing the dotted lines on the diagrams *M* and *N* in Fig. 672 (*b*), the exhaust going through the left port and the steam through the right port. As the process is so nearly like the preceding, the diagrams have not been drawn, but the student should follow the valve through the different positions, and note the effects on the diagrams. To assist him in this, the corresponding points have been numbered as in the foregoing figures.

2045. Lead.—A valve is said to have **lead** when it commences to open the steam-port just before the piston reaches the end of the stroke. The amount of lead is measured by the distance between the edge of the valve and the edge of the port from which the valve is traveling. In Fig. 673, the lead is the distance *a b*. Most engineers give their valves lead in order to have the clearance-space filled with

steam at boiler-pressure when the piston begins its stroke. The effect of lead on the angular advance of the eccentric

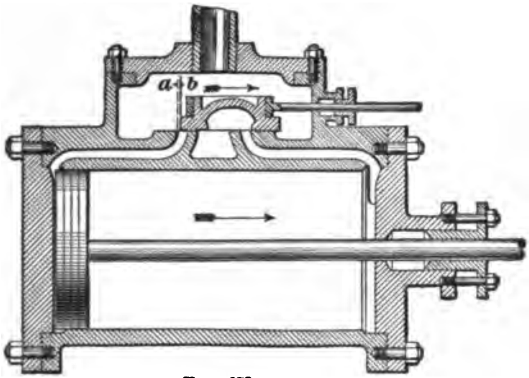


FIG. 673.

is evidently the same as an increase of lap; i. e., it increases the angular advance.

2046. In Fig. 674 is shown a sectional view of a plain slide-valve with its center *n* in line with the center *m* of the exhaust-port *E*. The valve takes this position during

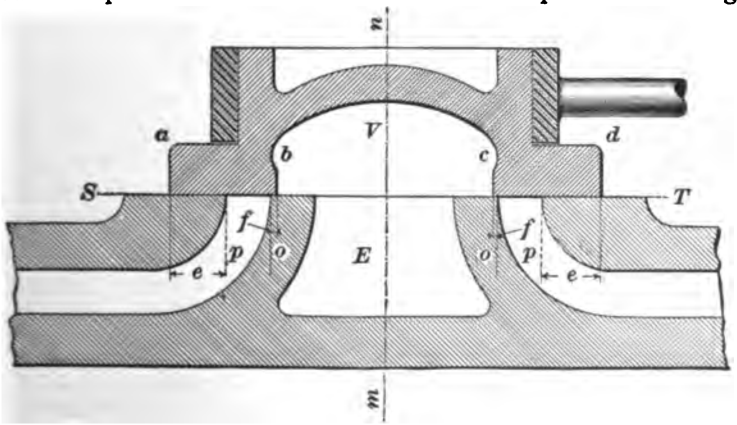


FIG. 674.

the interval between the point of release of the steam from the head end of the cylinder, and the point of compression of the steam in the crank end of the cylinder, during the forward stroke of the piston, and conversely for

the backward stroke. $S\ T$ is the valve-seat. The flange face $a\ b$ or $c\ d$ is the lip of the valve. The portion e of the flange face is the **outside** or **steam lap** of the valve, while portion f is the **inside lap.**

2047. Effects of Lap.—The study of Figs. 670 to 672 should show the effects caused by varying the lap. Thus, in Fig. 671 (*a*), it is evident that if the outside lap had been less, the valve would not close the left port when its center was in the position shown; consequently, the piston must move farther ahead before the valve can move back far enough to close the port. This, of course, makes the cut-off take place later in the stroke, and shortens the expansion. It is likewise evident that if the valve had more lap, this extra lap would extend beyond the port when the center of the valve was in the position shown. Therefore, the valve would cut off earlier in the stroke, and the expansion would be lengthened. Hence, *increasing the outside lap means an earlier cut-off and an increased expansion, while decreasing the outside lap means a later cut-off and a diminished expansion.*

Considering the inside lap, it is evident from Fig. 671 (*b*) that, if the inside lap had been less, the exhaust-port would not have closed so soon, and, consequently, the compression would have begun later; had the inside lap been greater, the compression would have begun earlier. Fig. 672 (*a*) shows that, with a diminished inside lap, the exhaust (usually termed **release**) would begin earlier, while with an increased inside lap, the release would have taken place later in the stroke. Hence, *increasing the inside lap increases compression and delays the release, while diminishing the inside lap decreases compression and hastens release.*

TO SET THE PLAIN SLIDE-VALVE AND ADJUST THE ECCENTRIC.

2048. In order to set the valve, we must first bring the crank to either its *head* or *crank* dead-center position. These occur respectively as the piston completes its backward and its forward strokes, when the centers of the cross-

head pin, crank-pin, and crank-shaft all lie in the same straight line.

2049. To Find the Dead Centers.—Make a fine, clear mark on the cross-head, then, while an assistant rotates the fly-wheel *in the direction opposite to that in which the engine is to run*, or backwards, follow the mark on the cross-head with a sharp instrument until it reaches successively the two extreme points of its travel, and at these points make marks on the guide-bar opposite the cross-head mark.

After this has been done for both head and crank positions of the cross-head, the engine should again be rotated *backwards* very slowly, and the accuracy of the guide-bar marks tested. We now have the dead-center points, since the centers of the cross-head pin, crank-pin, and crank-shaft will lie in the same straight line whenever the cross-head mark comes opposite either one of the guide-bar marks.

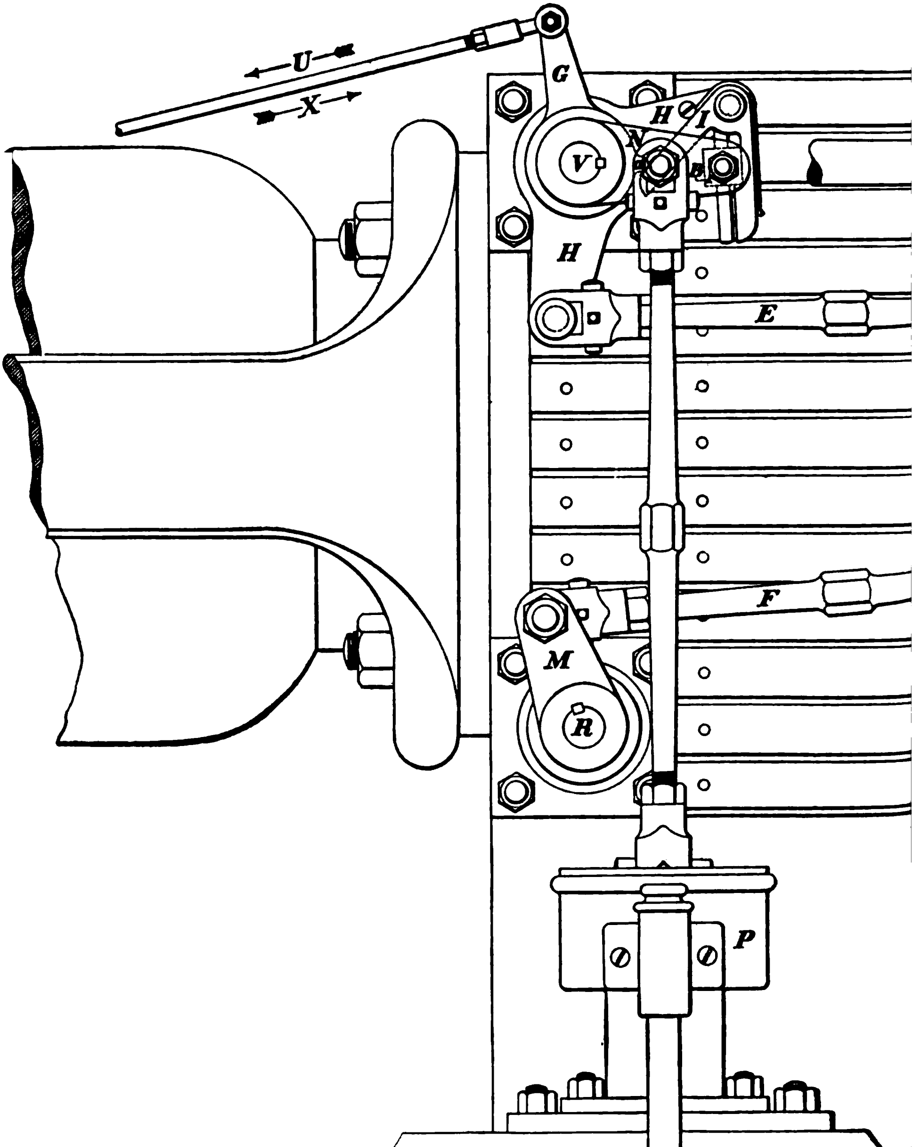
2050. To Set the Slide-Valve.—Remove the steam-chest cover by loosening the nuts with which it is screwed down, as shown in Fig. 668. Then revolve the crank *forwards*, or *in the direction in which it is to run*, until the cross-head mark coincides with the head guide-bar mark. Then if the eccentric-rod is *directly connected* to the valve-stem, that is, if the direction of motion of both the eccentric-rod and valve-stem is always the same, place the eccentric on the shaft a little more than a right angle *ahead* or in advance of the crank. But if the eccentric-rod is *cross-connected* to the valve-stem, that is, if its direction of motion is always directly opposite to the motion of the valve-stem, place the eccentric on the shaft a little more than a right angle *behind* or following the crank. Continue in either case to increase the angle between the eccentric and crank by turning the eccentric on the shaft, till the point *a* of the valve, Fig. 674, coincides with the point *p*. Then rotate the engine *forwards* till the cross-head mark coincides with the crank guide-bar mark, and see if *d*, Fig. 674, coincides with *p* of the right-hand port. If so, the valve is set correctly, but if *d* has passed *p*, the valve-stem *13*, Fig. 667,

must be removed and shortened an amount equal to one-half the distance between *p* and *d*; and if *d* does not come up to *p*, that is, if the right-hand port remains open, the valve-stem must be lengthened an amount equal to one-half the distance between *d* and *p*. The valve-stem now having the proper length, rotate the fly-wheel forwards till the cross-head mark again coincides with the head guide-bar mark, replace the valve-stem, and turn the eccentric on the shaft until the distance between *p* and *a* is equal to the desired lead, and firmly secure the eccentric to the shaft. Replace the steam-chest cover, as the slide-valve is set.

The lead usually given to a plain slide-valve is about $\frac{1}{16}$ of an inch for quiet running, but at any time it may be increased or diminished without opening the steam-chest, simply by turning the eccentric very slightly forwards or backwards.

2051. Slide-valve engines are made to cut off at different points in the stroke, according to the conditions under which they are to be operated. That is, the point of cut-off *2*, Fig. 681, may be made to occur earlier or later in the stroke than the figure represents. The point of cut-off is expressed in the form of a ratio, or coefficient. Thus, in Fig. 681 the length of the stroke is represented by the length of the line *A Z*, which is equal to the length of the diagram, and for a stroke of 42 inches, this line may be divided into 42 equal divisions, making the length of each division represent one inch. Then, by producing the line *2–10*, we see that the steam is cut off when the piston has traveled 28 inches, or $\frac{28}{42} = \frac{2}{3}$ of its stroke.

2052. The **ratio of expansion** is the number of times the volume of the live steam in the cylinder at the instant of cut-off is increased during the period of expansion. It is determined by dividing the length of the stroke by the distance through which the piston has moved when cut-off occurs. In the case just given, the stroke is 36 inches; cut-off occurs at 24 inches. The ratio of expansion is then $\frac{36}{24} = \frac{3}{2} = 1\frac{1}{2}$, that is, the steam expands to one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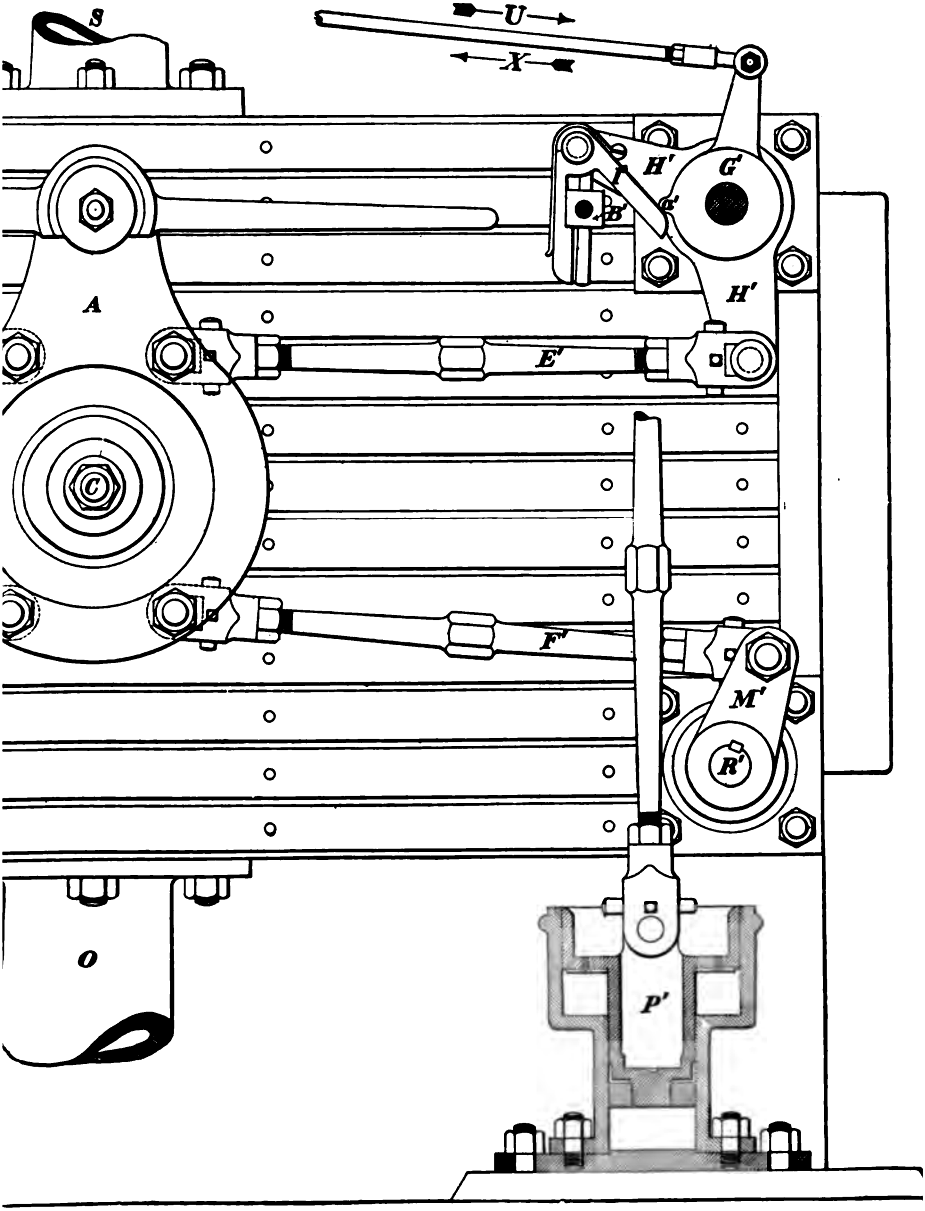
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and a half times its volume at the point of cut-off, or its volume is increased by the expansion in the cylinder an amount equal to one-half of what it was at cut-off.

In practice, the point of cut-off can be obtained directly from the engine. Measure the distance between the dead-center points as marked on the guide-bars; this will be the length of the stroke. Take off the steam-chest cover, and with the piston at the head end of the cylinder, slowly rotate the engine forwards until the head edge of the slide-valve coincides with the head edge of the steam-port. Then measure the distance between the head dead-center guide-bar mark and the mark on the cross-head; divide this latter quantity by the one first taken, and the result will be the cut-off required, in a fraction of the stroke. Plain slide-valves usually cut off between $\frac{1}{2}$ and full stroke.

CORLISS VALVE-GEAR.

2053. As has been stated before, the plain slide-valve involves all the principles made use of in any of the more complicated forms of valve-gear at present in use. The *Corliss valve-gear* is, however, being so extensively employed in different kinds of machinery, that a short description of its working parts and principles is here given.

In Fig. 675 is shown a side elevation of this valve-gear, and in Fig. 676 a section through the cylinder and valves.

It has four separate and distinct valves. Two of these, v and v', Fig. 676, connect directly with the steam-chest d and steam-pipe s, and are called steam-valves. They are rigidly connected with the cranks N and N', Fig. 675, N' being removed in order to show more clearly the disengaging link I'. The other two valves, r and r', Fig. 676, connect directly with the exhaust-chest l and the exhaust-pipe o, and are called exhaust-valves; they are rigidly connected with the cranks M and M', Fig. 675. All the valves are cylindrical in form, and extend across the cylinder above and below, respectively.

A, Fig. 675, is a disk or wrist-plate, which is made to rock

upon a stud C, by the eccentric-rod B, connecting it with an eccentric on the crank-shaft.

There are four valve-stems: E and E', which connect the wrist-plate A with the bell-cranks H and H' of the steam-valves, and F and F', which connect the wrist-plate A with the cranks M and M' of the exhaust-valves. The valve-stems can be lengthened or shortened as the case may require, and the action of any one valve may be regulated independently of the other three. As the wrist-plate A rocks backwards and

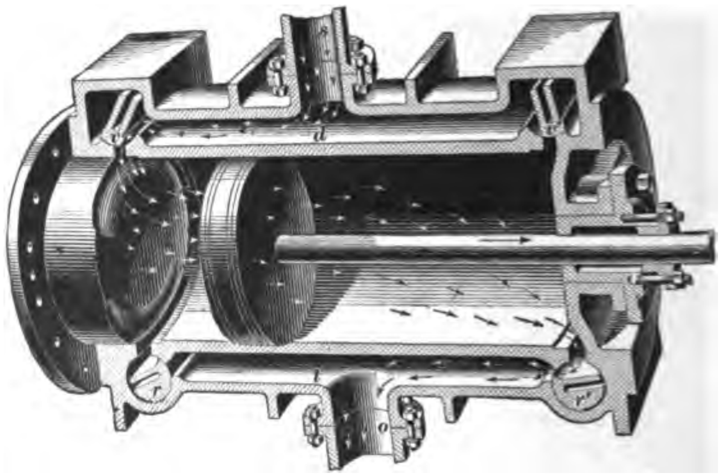

FIG. 676.

forwards, the exhaust-valves R and R', which are rigidly connected with their cranks M and M', rock with it. The bell-cranks H and H', which are provided with the disengaging links shown at I and I', are also given this rocking motion, and by hooking on to the blocks B and B', which are rigidly connected to the cranks N and N', open the steam-valves V and V'.

The projections a and a' on the two trip collars G and G' unhook these disengaging links I and I', after they have rotated the valves V and V' through a certain angle, and the cranks N and N' are pulled back to their first positions by the vacuum-air dash-pots P and P', against the resistance

of which the valve-cranks *N* and *N'* were raised. The movements of the valves open and close the steam and exhaust ports of the cylinder at the proper intervals. The pins of the valve-stems are so located on the wrist-plate that the steam-valves *V* and *V'* have their quickest movement while the exhaust-valves *R* and *R'* have their slowest movement, and the exhaust-valves have their quickest movement while the steam-valves have their slowest movement. As a consequence of this arrangement, the steam and exhaust valves have entirely independent movements, and the inlet-ports may be suddenly opened full width by the quick movement of the steam-valves, while the exhaust-valves are practically motionless. The advantage of this valve-gear is that it permits an earlier cut-off, with a greater range and a more perfect steam distribution, than is attained with the plain slide-valve.

Engines fitted with the Corliss valve-gear can not run at much more than 90 revolutions per minute.

INDICATORS AND INDICATOR-CARDS.

DESCRIPTION OF THE INDICATOR.

2054. In Fig. 681 and 682 are given diagrams (*1–2–3–4–5–6*) in which vertical distances represent pounds pressure per square inch, and horizontal distances the position of the piston in its stroke. Such a diagram is called an **indicator-diagram.** Indicator-diagrams are obtained by making use of an instrument called an **indicator,** Fig. 677, which is fitted to the steam-engine cylinder, as shown in Fig. 679. Holes are drilled into the clearance-spaces of the steam-cylinder (see *H* and *C*, Fig. 679), and connected with a pipe *O*, having a three-way cock *Q* in the middle. The indicator is securely fitted to the arm *F* of the three-way cock by inserting the projection *s* (see Fig. 678) in the end of the arm, and tightening up by the nut *r*.

It is the office of the three-way cock to check the passage of the steam when the indicator is not in use, but it can be

so turned as to give a free passage of steam through *H* and *F*, while closing it through *C*, or to give a free passage through *C* and *F*, while closing it through *H*. Referring now to Fig. 678, which is a sectional view of the indicator, *a* is the cylinder of the indicator in which the piston *g* slides. The spring *d* resists any upward motion of the piston *g*, but when such a motion is given to the piston, it is transmitted through the piston-rod *e* and the link *i* to the point *k* of the lever *n k p*. These parts are so adjusted that, as the lever

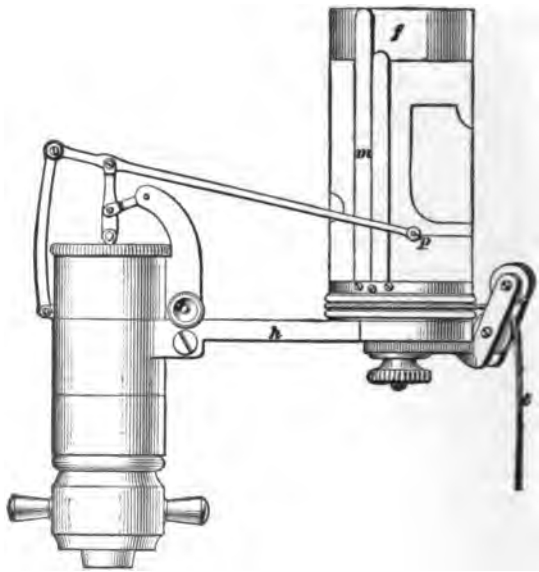

FIG. 677.

swings about *n* as a center, a pencil-lead at *p*, the extremity of the arm *n k p*, will mark a straight vertical line on the drum *f*. If, now, we open the pipe-connection *H Q F*, Fig. 679, to a free passage of steam from the steam-cylinder to the indicator (the passage *Q C* being closed by the cock at *Q*), it is evident that as the steam-pressure in the steam-cylinder varies during a stroke of the engine-piston, the movement of the indicator-piston *g*, Fig. 678, will be effected by the changing steam-pressure, and since the spring *d* of the indicator is so made that it will require a definite number of

pounds pressure per square inch on the piston *g* to compress it sufficiently to move the pencil-lead at *p* vertically one inch on the drum *f*, therefore the pencil-lead at *p* will mark on the drum *f* vertical lines proportional to the pressure behind the piston, during the various points of its stroke. If we now close the passage *H Q* to steam and open the passage *C Q F*, by turning the cock at *Q*, the pencil will in this case

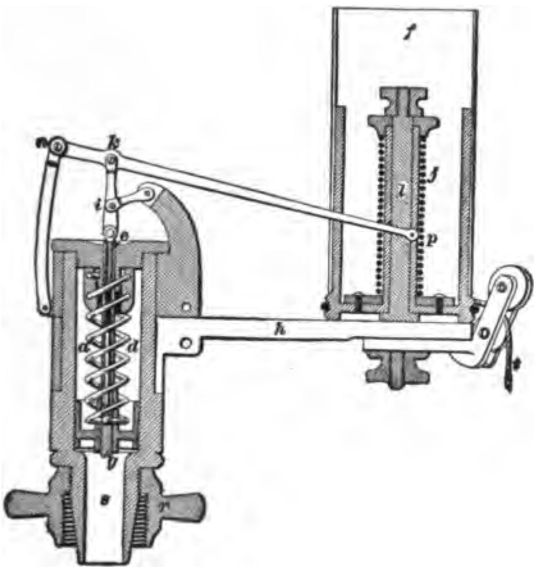

FIG. 678.

have a vertical movement proportional to the steam-pressure behind the piston in the crank end of the steam-cylinder.

2055. The **scale** of an indicator-spring is the number of pounds pressure per square inch on the indicator-piston necessary to give the pencil-lead a movement through a vertical distance of one inch, and it should not be less than ½ the boiler-pressure under which the engine is operated.

The spindle *l*, Fig. 678, is firmly fixed to the bar *h*, and is also connected to the drum *f* by means of the spring *j*. If, now, the cord *t*, which is wound on the drum, is pulled, the drum *f* will rotate against the action of the spring, but it

will, in turn, be rotated back to its first position by the spring when the pull on the cord t is discontinued.

From this it is evident that, if we pull and release the

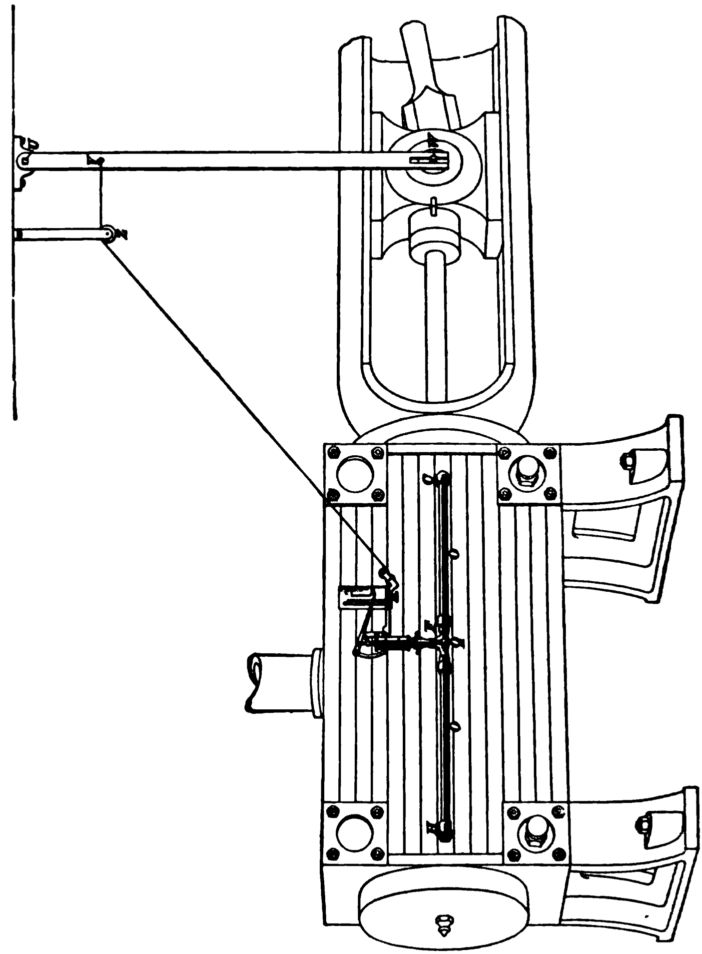

FIG. 679.

string by a forward and backward motion of the hand, a corresponding rotary motion will be given to the drum. When the indicator is in use, such a motion is thus given by means of the lever $U\ V\ W$ and the pulley Z, Fig. 679.

This arrangement is termed a **reducing motion,** because it enables us to take an indicator-card which will be less in length than the stroke of the engine. The lever is held in position at the ceiling by a pin *U*, and its lower end, which is slotted, is made to follow the motion of the cross-head by means of the pin *W*, clearly shown in the figure. The pin *U* should be directly over the pin *W* when the cross-head is in the center of its stroke. The *effective length* of the lever *U V W* is the distance *U W* taken when the cross-head is in the center of its stroke.

2056. To determine at what point the cord of the indicator-drum is to be fastened to the lever, in order to give the drum a rotary movement through a distance equal to the length of the indicator-card, when the effective length of the lever, the length of the stroke of the piston, and the length of the card are given:

Rule.—*Multiply the effective length of the lever in inches by the length of the card in inches, and divide this product by the length of the stroke in inches; the quotient is the distance in inches below the center of the pin U at which the cord is to be attached to the lever.*

EXAMPLE.—For the engine shown in Fig. 679, the stroke is 36 inches; the effective length of the lever is 72 inches, and the length of card desired is 3.5 inches; what is the distance of the point on the lever below the center of the fulcrum, at which the cord is to be attached?

SOLUTION.— $\frac{72 \times 3.5}{36} = 7$ in. Ans.

If, when the crank is on the *head* dead-center, we pass the cord over the pulley *Z*, Fig. 679, and fasten it at *V*, after drawing it just tight enough to rotate the drum through about half an inch, it is evident that when the engine is running, the drum will be given a rotary motion, backwards and forwards, corresponding to the stroke of the engine. The cord should only be fastened to the reducing motion during the time in which a card is being taken. It must also be remembered that the length of the indicator-diagram has nothing whatever to do with the results obtained from

it, but is made less than the stroke because the drum will not rotate so great a distance.

DIRECTIONS FOR TAKING INDICATOR-DIAGRAMS.

2057. Having everything arranged as explained, and the engine running under its usual load, take a piece of paper about seven inches long and three and one-half inches wide, and fasten it around the drum by passing the ends under the card-holders *m*, Fig. 677. Now, connect the cord *t* to the reducing motion, and let the pencil-lead at *p* press lightly against the drum as it rotates. A straight line will be made on the paper. This is the atmospheric line *A Z*,

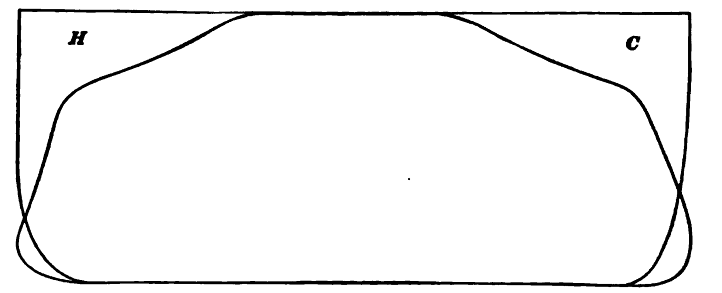

FIG. 680.

Fig. 681. Next, turn the cock at *Q* so as to admit steam to the indicator from *H*, Fig. 679, the head end of the cylinder, and the pencil-lead will move up and down as the piston of the engine goes forwards and back.

Turn the cock again and admit steam to the indicator from the crank end of the steam-cylinder, and the pencil-lead will again move up and down, having in each case drawn such a figure on the paper as is shown in Fig. 677 on the drum. In Fig. 680 are shown the head and crank cards, *H* and *C*, as they were drawn by the pencil during the two strokes of the piston.

Before removing the indicator-card from the drum, shut off the steam and disconnect the drum-cord from the reducing motion.

2058. In Fig. 680, H is the diagram from the head end of the steam-cylinder, and C is the diagram from the crank end.

If desired, these may be taken on separate pieces of paper, as shown in Figs. 681 and 682. The actual diagrams shown

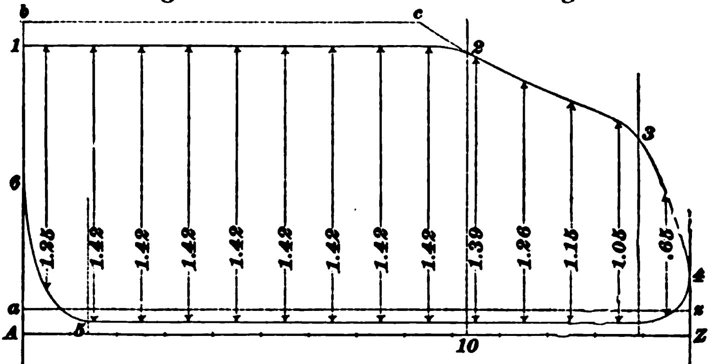

FIG. 681.

in Fig. 680 are not so regular as the theoretical ones in Fig. 672 (b). The different points of the stroke are, however, quite clearly defined.

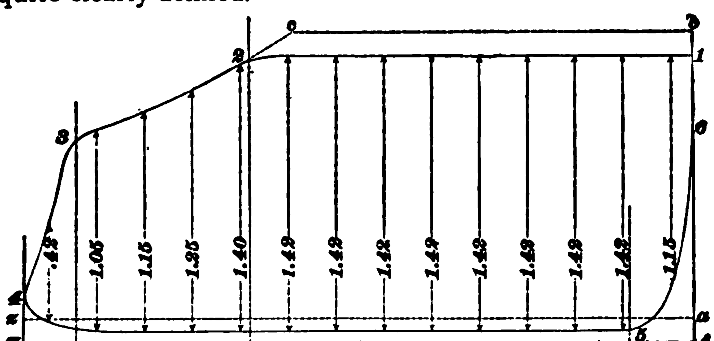

FIG. 682.

Thus: *1* is the beginning of the stroke.
2 is the point of cut-off.
3 is the point of release.
4 is the end of the stroke.
5 is the point of compression.
6 is the point of admission.

6–1 is the admission line.
1–2 is the steam line.
2–3 is the expansion curve.
3–4–5 is the period of release.
4–5 is the back-pressure line.
5–6 is the compression curve.
A Z is the atmospheric line.

2059. To determine from an indicator-card, taken from the cylinder of an engine, at what point in the stroke of the engine *cut-off* occurs:

Rule.—*Measure along the atmospheric line the distance in inches between the extreme projections of the card. Measure also the distance in inches between the projections of the points of admission and cut-off on the atmospheric line, and divide the latter quantity by the former.*

EXAMPLE.—In Fig. 681, the distance between A and Z is 3.5 inches. The distance between A and *10* is 2.33 inches; when did the valve cut off?

SOLUTION.— $\frac{2.33}{3.5} = .666 = \frac{2}{3}$; therefore, the cut-off occurs at $\frac{2}{3}$ stroke. Ans.

INDICATED HORSEPOWER.

2060. The **horsepower** developed by the engine may be found directly from the area of the indicator-diagram. It is more convenient, however, to use the diagram to find the "mean effective pressure" exerted on the piston.

2061. The **mean effective pressure,** or M. E. P., is defined as the average net pressure urging the piston forwards during its entire stroke in one direction. The mean effective pressure may be found in two ways:

2062. The area of the diagram in square inches may be found by an instrument called the planimeter; *the M. E. P. is then found by dividing the area of the diagram in square inches by the length of the diagram in inches, and multiplying by the scale of the spring.*

EXAMPLE.—The area of the diagram is 4.2 sq. in., and the length is 3.5 in.; a 40 spring being used, find the M. E. P.

SOLUTION.— $\frac{4.2}{3.5} \times 40 = 48$ lb. per sq. in., M. E. P. Ans.

2063. Where a planimeter is not available, the following method of finding the M. E. P. is fairly rapid and accurate:

Draw tangents to each end of the diagram perpendicular to the atmospheric line. Divide the horizontal distance between the tangents into 10 or more equal parts. (10 or 20 parts are the most convenient, but any other number may be used.) Indicate by a dot on the diagram the center of each division, and draw lines through these dots, parallel to the tangents, from the upper line to the lower line of the diagram. On a strip of paper mark off successively the lengths of these lines, the total length thus representing the sum of all the lines. Divide this total length by the number of lines used, and multiply the quotient by the scale of the spring. The result will be the M. E. P.

EXAMPLE.—The projection of the diagram shown in Fig. 682 upon the atmospheric line is *A Z*; that is, lines perpendicular to this line, drawn through the extreme ends *1* and *4* of the diagram, cut it (the atmospheric line) in *A* and *Z*. *A Z* is divided, in this case, into 14 equal spaces. The length of each of the perpendicular lines drawn through the diagram opposite the centers of these spaces is marked on the line itself, and the sum of these lengths is 18.11 inches. The scale of the spring used in obtaining the diagram was 40 pounds; therefore, $\frac{18.11}{14} \times 40 = 51.74$ pounds per square inch = the M. E. P. of the bottom-end diagram.

EXAMPLE.—The projection of the diagram, Fig. 681, upon the atmospheric line is the distance *A Z*, and it is divided, in this case, into 14 equal spaces. The length of each of the perpendicular lines drawn through the diagram opposite the centers of these spaces is marked on the line itself, and the sum of these lengths is 17.78 inches. The scale of the spring is 40 pounds; therefore, $\frac{17.78}{14} \times 40 = 50.8$ pounds per square inch = the M. E. P. of the top-end diagram.

Therefore, the M. E. P. in the cylinder during a complete revolution of the crank is $\frac{51.74 + 50.8}{2} = 51.27$ pounds per square inch.

2064. The reason for dividing the diagram into 10 parts instead of some other number is that it shortens the work of calculation. Thus, in the two examples just given, if the number of divisions had been 10 instead of 14, and the sum of the ordinates had been 12.94 inches, the mean ordinate would have been $\frac{12.94}{10} = 1.294$ inches, and the M. E. P., $1.294 \times 40 = 51.76$ lb. per sq. in. All that is necessary is to add the ordinates and shift the decimal point one place to the left to obtain the mean ordinate when the diagram is divided into 10 equal parts. This method saves the time required to divide by some inconvenient number, such as 14.

2065. In Figs. 681 and 682, the vertical line *a b* represents the boiler-pressure, and, therefore, the dotted line *b c* is the line that the indicator-pencil would trace if the full boiler-pressure were maintained until point of cut-off. The line *b c* is not drawn by the indicator as ordinarily used; it has been added for sake of illustration.

2066. We have now all the material required for finding the work done in the engine-cylinder expressed in horsepower units.

Work is the product of force into the distance through which it moves. In the case of the engine-cylinder, the total force is the M. E. P. per square inch multiplied by the area of the piston; and the distance moved through in one minute is the number of strokes per minute multiplied by the length of the stroke.

2067. Rule.—*To find the* ***indicated horsepower*** *developed by the engine, multiply together the M. E. P. per square inch, the area of the piston, the length of stroke, and the number of strokes per minute. This gives the work per minute in foot-pounds. Divide the product by 33,000; the result will be the indicated horsepower of the engine.*

Let I. H. P. = indicated horsepower of engine;
P = M. E. P. in pounds per square inch;
A = area of piston in square inches;
L = length of stroke in feet;
N = number of strokes per minute.

Then, the above rule may be expressed thus:

$$\text{I. H. P.} = \frac{PLAN}{33,000}. \qquad \textbf{(143.)}$$

2068. The number of strokes per minute is twice the number of revolutions per minute. For example, if an engine runs at a speed of 210 revolutions per minute, it makes 420 strokes per minute. A few types of engines, however, are single-acting; that is, the steam acts on only one side of the piston. Such are the Westinghouse, the Willans, and others. In this case, only one stroke per revolution does work, and, consequently, the number of strokes per minute to be used in the above rule is the same as the number of revolutions per minute. As most steam-engines are double-acting, no mention is generally made of this fact. When the dimensions of an engine are given, unless it is stated that the engine is single-acting, it may be assumed that a double-acting engine is meant and that work is done during each stroke.

EXAMPLE.—The diameter of the piston of an engine is 10 inches, and the length of stroke 15 inches. It makes 250 revolutions per minute, with a M. E. P. of 40 pounds per square inch. What is the horsepower?

SOLUTION.—As it is not stated whether the engine is single or double acting, assume that it is double-acting. Then, the number of strokes is $250 \times 2 = 500$ per minute. Applying formula **143,**

$$\text{I. H. P.} = \frac{PLAN}{33,000} = \frac{40 \times \frac{15}{12} \times (10^2 \times .7854) \times 500}{33,000} = 59.5 \text{ H. P.}$$

2069. Approximate Determination of M. E. P.—To approximately determine the M. E. P. of an engine, when the point of apparent cut-off is known and the boiler-pressure, or the pressure per square inch in the boiler from which the supply of steam is obtained, is given:

Rule.—*Add 14.7 to the gauge-pressure, and multiply the result by the number opposite the fraction indicating the point of cut-off in Table 44. Subtract 17 from the product and multiply by .9. The result is the M. E. P. for good, simple non-condensing engines.*

Or, letting p = gauge-pressure;
k = a constant (see Table 44);
M. E. P. = mean effective pressure.

Then, M. E. P. $= .9\,[k\,(p + 14.7) - 17]$. **(144.)**

TABLE 44.

Cut-off.	Constant.	Cut-off.	Constant.	Cut-off.	Constant.
$\frac{1}{6}$	.566	$\frac{3}{8}$	.771	$\frac{2}{3}$	.917
$\frac{1}{5}$	.603	.4	.789	.7	.926
$\frac{1}{4}$	.659	$\frac{1}{2}$	.847	$\frac{3}{4}$	.937
.3	.708	.6	.895	.8	.944
$\frac{1}{3}$	.743	$\frac{5}{8}$	.904	$\frac{7}{8}$	.951

2070. If the engine is a simple condensing engine, subtract the pressure in the condenser instead of 17. The fraction indicating the point of cut-off is obtained by dividing the distance that the piston has traveled when the steam is cut off by the whole length of the stroke. For a $\frac{2}{3}$ cut-off, and 92 pounds gauge-pressure in the boiler, the M. E. P. is, by the formula just given, $.9[.917(92 + 14.7) - 17] =$ 72.6 lb. per sq. in.

Example.—Find the approximate I.H.P. of a 9"×12" non-condensing engine cutting off at $\frac{1}{2}$ stroke, and making 240 revolutions per minute. The boiler-pressure is 80 pounds, gauge.

Solution.— $80 + 14.7 = 94.7$. Using formula **144** and Table 44, the constant for $\frac{1}{2}$ cut-off is .847, and .847 × boiler-pressure = .847 × 94.7 = 80.21. M. E. P. = (80.21 − 17) × .9 = 56.89 lb. per sq. in. Then, from formula **143**,

$$\text{I. H. P.} = \frac{PLAN}{33{,}000} = \frac{56.89 \times \frac{12}{12} \times (.7854 \times 9^2) \times 240 \times 2}{33{,}000} = 52.64 \text{ H. P.}$$

Ans.

2071. Piston Speed.—The product LN of formula **143** gives the total distance traveled by the piston in one minute. This is called the **piston speed.** It is usual to take the stroke in inches. Then, to find the piston speed, multiply the stroke in inches by the number of strokes, and divide by 12, or, letting S represent the piston speed, $S = \frac{lN}{12}$, where

The

follows.

2072. Formula

that is

2073.

2074.

For example: indicator-diagrams, taken from an engine while running under full load, and having a piston speed of 498 feet per minute, show an *indicated horsepower* of 242.7. With the same piston speed, and running under no load, the indicator-diagrams show an *indicated horsepower* of 75.2. Then, $242.7 - 75.2 = 167.5 =$ the *actual horsepower* of the engine.

2075. The **mechanical efficiency** of an engine is the ratio of the *actual horsepower* to the *indicated horsepower;* or it is the per cent. of the mechanical energy developed in the cylinder which is utilized in the doing of useful work.

2076. To find the efficiency of an engine, when the *indicated* and *actual horsepowers* are known:

Rule.—*Divide the actual horsepower by the indicated horsepower.*

Let N. H. P. = the net, or actual, horsepower;
I. H. P. = the indicated horsepower;
E_m = efficiency of engine.

Then, $$E_m = \frac{\text{N. H. P.}}{\text{I. H. P.}} \qquad \textbf{(146.)}$$

EXAMPLE.—The indicator-diagrams taken from an engine running under full load show the I. H. P. to be 238.5. The diagrams taken when the engine is running under no load show a horsepower of 39.7. (*a*) What is the net H. P. developed by the engine? (*b*) What is the efficiency of the engine?

SOLUTION.—(*a*) Net H. P. = I. H. P. − friction H. P. $= 238.5 - 39.7 = 198.8$. Ans.

(*b*) By formula **146,** the efficiency is

$$\frac{\text{N. H. P.}}{\text{I. H. P.}} = \frac{198.8}{238.5} = 83.4\%. \quad \text{Ans.}$$

The mechanical efficiency of a good engine may be from 75 to 90 per cent.

The efficiency of steam-engines varies greatly; it is, however, usually taken at 66 per cent. in all approximate determinations. That is, ordinary practice shows that with the types of engine commonly used only about .66 or $\frac{2}{3}$ of the power developed in the cylinder is actually available.

2077. We will now consider an example, to show how the above rules may be used in practical work.

EXAMPLE.—Determine approximately the dimensions of a single-cylinder, non-condensing engine to furnish 175 actual horsepower.

SOLUTION.—The I. H. P. of the engine will be about $\frac{1}{2}$ greater than the actual horsepower, or $175 \times \frac{3}{2} = 262$.

This is a large stationary engine; therefore, we should have a piston speed of between 500 and 900 feet per minute, say 600 feet per minute.

The cut-off may be taken at $\frac{1}{4}$ to insure good results, and the boiler-pressure may be assumed to be 80 pounds per square inch. From formula **144**, the M. E. P. is $.9 \times [.904(80 + 14.7) - 17] = 61.75$ pounds per square inch.

Letting d = diameter of cylinder,

$$\text{I. H. P.} = \frac{d^2 \times .7854 \times 61.75 \times 600}{33,000} = 262;$$

$$\text{or,} \quad d = \sqrt{\frac{262 \times 33,000}{.7854 \times 61.75 \times 600}} = 17.24 \text{ inches, say 17 inches.}$$

Taking the ratio of stroke to diameter of cylinder as 1.5, we have stroke $= 17 \times 1.5 = 25.5$, say 26 inches.

The number of revolutions of the crank would then be $\frac{600 \times 6}{26} =$ 138.5 revolutions per minute.

EXAMPLES FOR PRACTICE.

1. The mean effective pressures of two diagrams taken from the two ends of the cylinder of an 18" × 20" non-condensing engine, running at 200 R. P. M. (revolutions per minute), are, respectively, 57.6 lb. per sq. in. and 60.8 lb. per sq. in. long. What is the horsepower of the engine? Ans. 304.335 H. P.

2. The area of an indicator-diagram, as found by the planimeter, is 2.76 square inches. The length of the diagram is 2.4 inches, and the scale of the spring is 30. What is the M. E. P.? Ans. $34\frac{1}{2}$ lb. per sq. in.

3. The indicator-diagrams from an engine show a M. E. P. of 27.3 pounds per square inch. The engine has a 26" × 48" cylinder, and makes 68 revolutions per minute. Calculate the I. H. P. developed by the engine. Ans. 238.94 H. P.

4. Find the I. H. P. developed by an 8" × 12" engine, running at 260 revolutions per minute, the average M. E. P. being 32.61 pounds per square inch. Ans. 25.83 H. P.

5. (*a*) What is the piston speed of the engine of example 3? (*b*) of the engine of example 4? Ans. $\begin{cases} (a) \text{ 544 ft.} \\ (b) \text{ 520 ft.} \end{cases}$

CONDENSERS.

2078. In Fig. 683 is shown a condenser, of which Fig. 684 is a sectional view. The operation of this condenser may be explained as follows: When steam is admitted to the steam-cylinder, it causes the piston *P* to move first to the right and then to the left, as in the cylinder of a steam-engine, and since the air-pump piston *O* and the water-pump piston *Q* are both rigidly connected to *P* by the double piston-rod as shown, they are given the same motion

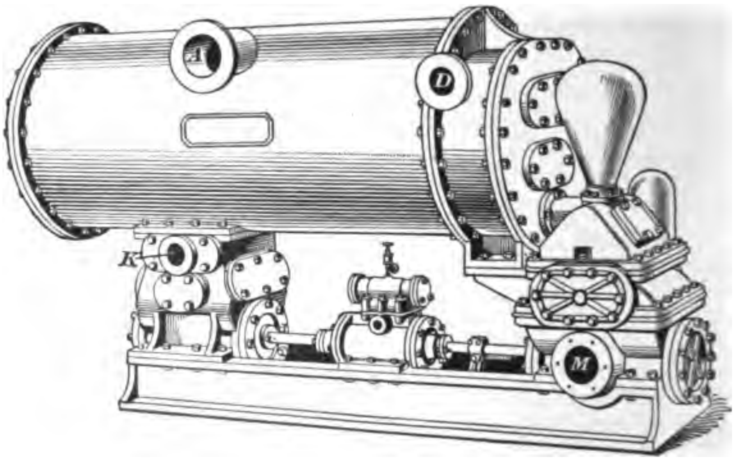

FIG. 683.

as *P*, with the following effect: The nozzle at *M* is connected by piping to a water-supply, through which water is drawn into and discharged from the circulating or water-pump cylinder by the movement of the piston *Q*, in the manner clearly shown by the arrows, Fig. 684. The valves *S*, *S* and *V*, *V* are automatically opened and closed by the pressure of the water below, and by the pressure of the water and springs above them. After the water is forced through the inlet *C* into the chamber *F*, it flows, as is indicated by the arrows, through the inner tubes of the lower layer of double tubing to the left, and having passed through their entire length, it returns through the space between

the outside of the inner and inside of the outer tubes into the chamber *G*. Fig. 685 shows more clearly the arrangement of this "double tubing." From *G*, Fig. 684, it passes

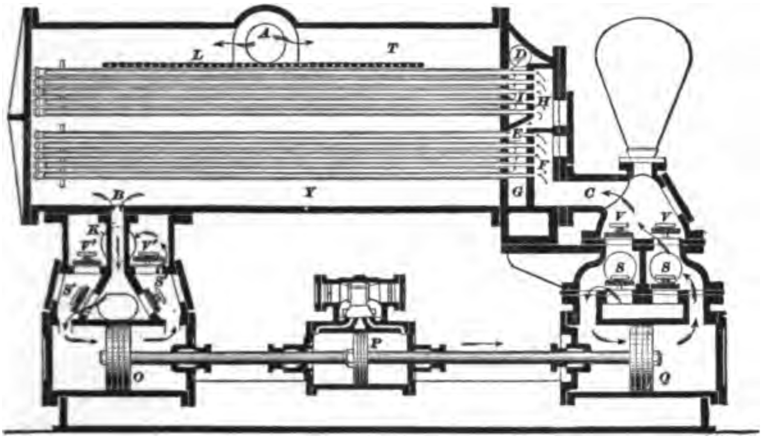

FIG. 684.

through *E* to *H*, and from *H* to *I* through the upper layer of double tubing, as has already been explained. From *I* it is discharged through the nozzle *D*, carrying with it all the heat it has received by coming in contact with the two layers of double tubing.

The nozzle at *A* is connected with the exhaust-pipe of the steam-cylinder of an engine. The movement of the air-pump piston *O* draws air through the orifice *B* from the

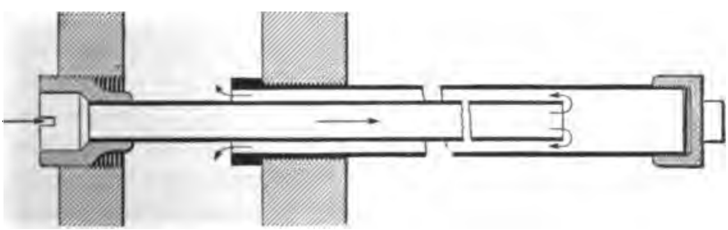

FIG. 685.

condenser-cylinder, and discharges it through the valves and the nozzle *K*, in a manner clearly indicated by the arrows. The valves *S'*, *S'* and *V'*, *V'* are opened and closed automatically by the pressure of the air beneath them, and by the

pressure of the air and springs above them. A partial vacuum is created in the condenser-cylinder Y by the action of the air-pump; this reduces the back pressure of the steam on the engine piston, and permits the exhaust steam to leave the engine-cylinder with much less resistance than it would encounter if it were discharged against the pressure of the atmosphere.

As the exhaust steam enters the condenser-cylinder through A, it strikes a scattering plate L, which distributes it among the tubes, and protects the upper rows of tubing from the cutting effect of a direct current of steam. By coming in contact with the cold tubes the steam is condensed and falls to the bottom of the condenser-cylinder as water; this water flows through B to the air-pump cylinder, from which it is discharged, and is then pumped into the boiler before cooling. By this means a supply of boiler feed-water is obtained at a temperature nearly as high as that of the condenser.

2079. The most important use of the condenser, however, is by means of the partial vacuum produced by the condensation of the steam to relieve the exhaust side of the piston from the pressure of the atmosphere. Without a condenser the exhaust must be forced out of the cylinder against the pressure of the outside air, about 14.7 pounds per square inch, and this pressure must be overcome by the pressure of the steam on the other side of the piston. With a good condenser the pressure against which the exhaust must leave the cylinder is reduced to not more than 3 or 4 pounds per square inch. There is thus an increase in the effective pressure which can be obtained with a given boiler pressure. This results in an increase in the power which the engine can develop, together with a reduction in the steam required to do a given amount of work. To illustrate, consider the cards shown in Figs. 681 and 682. If the pressure in the condenser-cylinder were 12 pounds below the pressure of the atmosphere, it is evident that the initial pressure need have been only $60 - 12 = 48$ pounds per square inch, in order to

have produced the same cards. The atmospheric line drawn by the indicator pencil would have been at $a\ z$ at a scale distance of 12 pounds above the old atmospheric line $A\ Z$, or 6 pounds above the back pressure line *4–5*. In effect every point on the card would be lowered a scale distance of 12 pounds.

STEAM-ENGINE GOVERNORS.

2080. Steam-engine governors are mechanical devices which automatically regulate the steam-supply of an engine, so that when the load on the engine is increased or decreased, or when the steam-pressure under which it operates changes, the speed of the engine will remain constant. It must not, however, be thought that the duty of the governor is to adjust the working conditions of an engine to any sudden variation of steam-pressure or load that may occur during the time of a single stroke of the piston. It is the office of the fly-wheel to respond to these rapidly changing conditions, and by the resistance which it offers to any rapid change in its velocity, to gradually absorb this sudden force in increasing and decreasing the number of its revolutions per minute. When the engine is not supplied with a fly-wheel, there are other rotating parts, such as the drum of a hoisting-engine, which serves the same purpose. Any variation of the speed of the fly-wheel is, however, met by the action of the governor, which increases or decreases the steam-supply, and thereby restricts the velocity of the fly-wheel within certain limits. The principle that insures the action of all steam-engine governors is that of the equalization of two opposing forces, which will occur only when the engine is running at its proper speed. Any variation of the speed tends to give one of these forces an increase over the other, which is expended in moving some mechanism for the adjustment of the steam-supply.

2081. Steam-engine governors may be divided into two classes: (1) **Throttling governors,** which throttle the steam in the supply-pipe, and (2) **automatic** or **adjustable cut-off governors,** which regulate the steam-supply by changing the point of cut-off of the valve.

2082. Throttling governors are usually of the pendulum or fly-ball type. One of these is quite clearly shown at *k*, *m*, *m'*, *n*, *o*, Fig. 667. When the engine is running, a rotary motion is given to the pulley *n* by means of the belt which runs over a pulley rigidly fastened to the crank-shaft. This motion is transmitted through the bevel-gears seen at *o* to the spindle *k*, which is secured to the fly-balls *m* and *m'*.

2083. Suppose the engine to be running at its proper speed; a balance will then exist between the gravity force and the centrifugal force due to the rotary motion, both of which are acting on the balls. If, now, from any cause, the speed lessens, the centrifugal force will diminish, and gravity, acting on the balls, will pull them down. This movement on the part of the balls will, in turn, be imparted to a balanced throttle-valve, which will be opened wider, causing an increase in the initial pressure of the live steam. The live steam will now, in consequence of the additional amount of work it is capable of doing, exert more energy on the piston and bring the speed back to its proper point. If, on the other hand, the speed be increased, the fly-balls will rise upwards in consequence of the centrifugal force becoming greater than the attraction of gravity, and the steam orifice of the throttle-valve will be diminished in area. This will lower the initial pressure; the steam will consequently exert a less effort, and the speed will drop to its proper point.

2084. As an example of the automatic adjustable cut-off governor, of which there are many forms, we will consider that usually employed on the Corliss type of engines, the valve-gear of which has already been described in Art. **2053.**

Referring to Fig. 686, we see that a rotary motion is imparted to the fly-balls *m*, *m*, by means of a belt *p*, pulleys

n and r, and bevel-gear connection o, similar to that already described when stating the principle of the throttling governor.

Suppose that the engine is running at its proper speed. The fly-balls will then be held in their normal position by the balance existing between the centrifugal and gravity forces acting on the fly-balls m, m. Suppose, now, the speed of the engine increases from any cause whatever; the centrifugal force acting on the fly-balls will also increase and will continue to pull them out, that is, to increase the

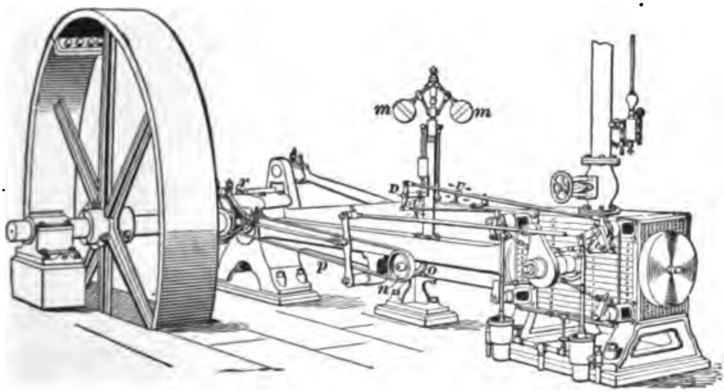

FIG. 686.

diameter of the circle in which they rotate, until a new balance is effected between it and the attraction of gravity. This movement of the fly-balls will be transmitted to the lever D, causing it to turn slightly about its center in the direction of the arrow X. The movement of D will cause the trip-collars G and G', Fig. 675, to turn through a small angle in such a direction that their projections a and a' will unhook the disengaging links I and I' earlier in the stroke of the engine. This will cause the point of cut-off to occur earlier in the stroke, and a decrease in the speed of the engine, on account of the reduction in the amount of steam admitted to the cylinder and an increased ratio of expansion of the steam under the same initial pressure. Should the speed from any cause diminish, a reverse operation would

be the result of the action of the governor. The fly-balls would drop slightly; D would turn as indicated by the arrow U, and the trip collars G and G' would be rotated in such a manner as to cause their projections a and a' to unhook the disengaging links I and I' later in the stroke; the cut-off would then occur later in the stroke, and a diminished ratio of expansion at the same pressure would bring the speed up to its proper point again.

SPECIAL TYPES OF ENGINES.

HOISTING-ENGINES.

2085. A **hoisting-engine** is usually a combination of two single-cylinder engines of exactly the same description

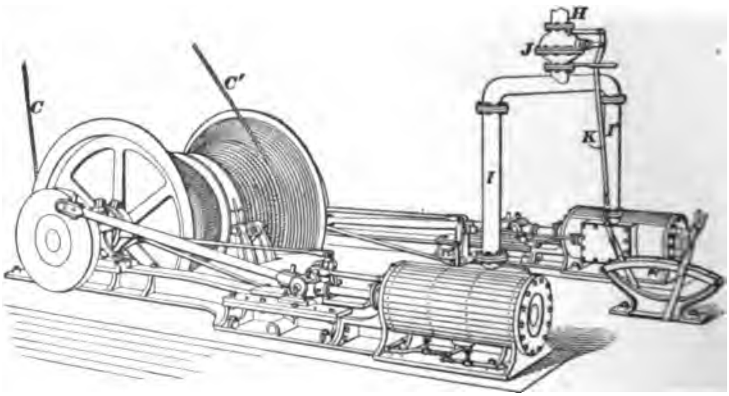

FIG. 687.

and dimensions, which have their cranks rigidly connected to a common crank-shaft, and take steam at the same pressure. Such a combination is called a **duplex engine.** In order to prevent the possibility of both cranks being on a dead center at the same moment, one crank is placed a distance of one right angle in advance of the other. In Fig. 687 is shown such an engine. The large double spiral drum performs the duty of a fly-wheel, while also doing duty as the drum on which the ropes C and C' are wound and unwound. It is evident that the engine must be so constructed

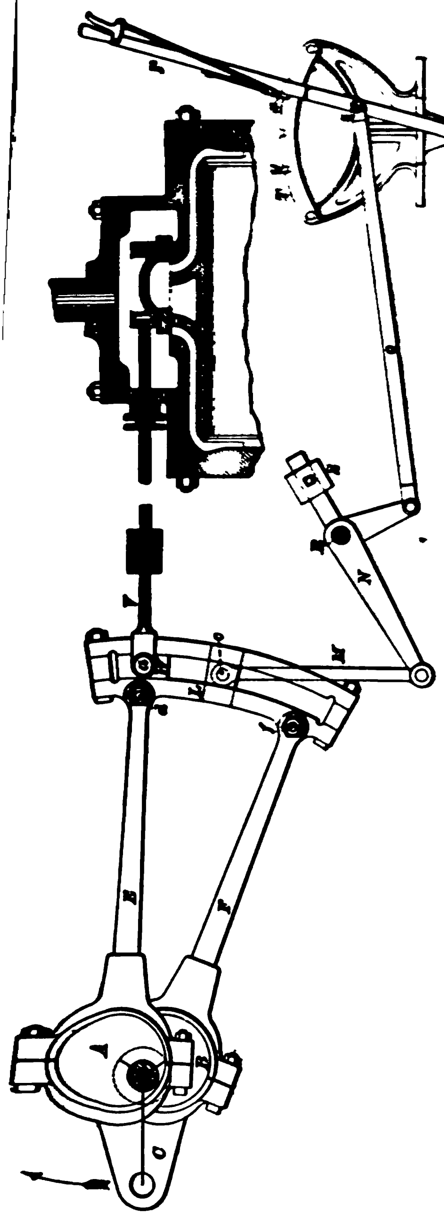

Fig. 688.

that the direction of rotation of the drum may be reversed at will. This introduces a new feature, namely, a **reversing-gear,** which must form a part of every engine of which the direction of motion is to be reversed. The most common form of reversing-gear is the Stephenson link-motion, which can be partly seen in Fig. 687, but is more clearly shown in Fig. 688; the lettering, however, applies alike to both figures.

2086. Let *O* be the center of rotation of the crank *C*, and suppose the arrow to represent the forward rotation of the engine. Then, *A* will be the forward eccentric and *B* the backward eccentric; *E* will be the forward eccentric-rod, and *F* the backward eccentric-rod.

The forward eccentric, for reasons already explained, must be slightly more than a right angle in advance

of the crank when it is directly connected, since it is to supply the means of operating the slide-valve when the engine is rotating forwards. The parts as shown are in the positions required to rotate the engine forwards. For the same reason, the backward eccentric *B* must be slightly more than a right angle behind the crank, when the engine is rotating forwards, so that when the engine is reversed, and *f* takes the place of *d*, *B* may be in advance of the crank when the engine rotates backwards.

L is the reversing-link; it has the form of an arc of a circle whose radius equals *O c*. The link-block *W* forms the connection between the valve-stem *V* and link *L*, and makes it possible for *L* to be moved through a distance *f d*.

There is a joint between *E* and *L* at *d*, and another between *F* and *L* at *f*. *N* is a bell-crank, and is rigidly connected to the "tumbling" shaft *R*, which is held in position by means of bearings. It is also jointed, as shown, to the lifting-rod *M* and the reach-rod *o*; *M* is connected to the center *c* of the link *L*, and the reach-rod *o* is connected at *z* to the reversing-lever *P*, which swings about *Q* as a center, and when moved is caught and held in its position by the spring-latch *x* catching in the notches of the sector *T*. *S* is simply a counterbalance which balances the weight of the other parts about *R* as a center.

2087. By a movement of the reversing-lever *P*, through the length of the sector from the notch at *x* to the notch *y*, the point *f* is brought in line with *a*, and so changes the relative position of the slide-valve (that is, of the port-openings, etc.), that the engine can no longer rotate as indicated by the arrow, but must reverse its direction in consequence of the full steam-pressure being brought to bear on the opposite side of the piston, as a result of this movement of the valve. Another important point, in connection with this link-motion, is the fact that if the reversing-lever is moved and secured so as to bring *a* between *d* and *c*, the valve-travel will be reduced, and the admission-port opening diminished, directly as the distance between

a and *c*, in *a*'s new position. When *c* reaches *a*, there will be no travel of the valve, and for points between *c* and *f* the valve-travel will again increase directly as the distance between *a* and *c* increases.

This means that, as in the case of an automatic governor, we can adjust the steam-supply to the load on the engine for either forward or backward rotation of the crank by a simple movement of the reversing-lever *P*, which, in this case, operates the reversing-gears of both cylinders in Fig. 687.

2088. This class of engines, as a rule, however, are governed by hand, by making use of the throttle-valve shown at *J*, and operating it by the lever *K* to check the flow of the steam-supply, as in the case of the throttling governor. *H* is the main steam-supply pipe, and steam is admitted to both cylinders at the same pressure through the branch pipes *I* and *I'*.

2089. Hoisting-engines are said to be **first-motion engines** when the drum is fastened directly on the crank-shaft, as shown in Fig. 687, and **second-motion engines** when the rotary motion is imparted to the drum through the medium of a small gear-wheel fastened on the crank-shaft, which meshes with a large gear-wheel on the drum-shaft.

HAULAGE-ENGINES.

2090. Haulage-engines, as in the case of hoisting-engines, usually consist of two single-cylinder engines of exactly similar dimensions, taking steam from the same source, and at the same pressure. They are placed side by side, transmit power through the same shaft, and have their cranks at right angles to each other. There are, however, slight differences in the conditions under which these engines operate in the "tail-rope" and "endless-rope" systems, which necessitate slight differences in their construction and operation.

2091. The **tail-rope haulage-engine** is one of exactly the same type as the hoisting-engine already

described in Fig. 687, except that the winding drums are usually parallel instead of conical. They should be reversible, and, since their speed varies, are usually governed by a throttle-valve operated by hand. They are also supplied with a suitable brake.

2092. An **endless-rope haulage-engine** is shown in Fig. 689. The engines A and B are connected to the

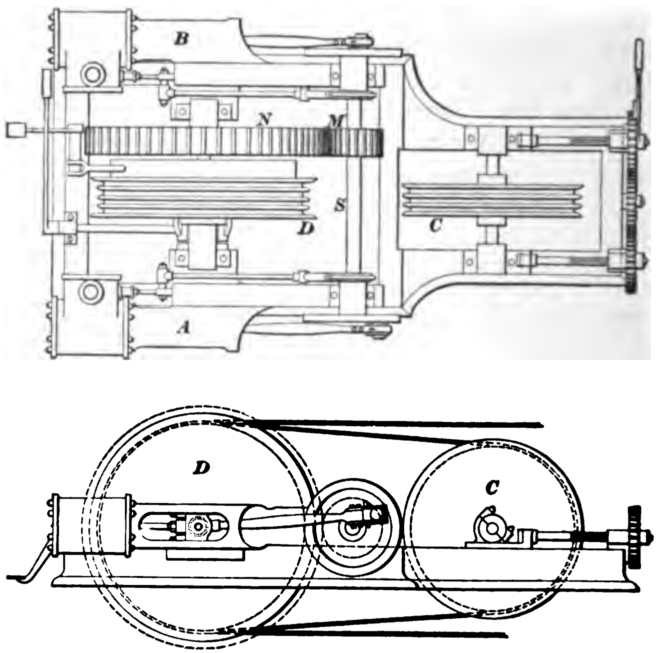

FIG. 689.

same shaft S, and transmit a rotary motion to the drum D through the gear-wheels M and N, an arrangement which constitutes *a second-motion engine*. The wire haulage-rope passes first over the drum D, and is then carried over the drum C, and, after being wound over them both, it passes off the larger drum. Since the rope is endless, that is, since its ends are spliced and it passes over a wheel at the other end of the line, there is no necessity of reversing the

engine; therefore, it is operated at a constant speed and is regulated by a throttling or automatic governor.

FAN-ENGINES.

2093. Fan-engines do not of themselves form a separate and distinct class which may be considered under this head on account of any marked peculiarity of construction which they possess. We may employ, in the driving of a fan, any engine which is capable of developing the necessary amount of power to operate the fan at the required speed. It is, therefore, evident that such an engine may be of either the simple, duplex, compound, or other form, its type being usually determined by a careful consideration of the power it is to develop and the pressure under which it is to be operated.

COMPOUND ENGINES.

2094. Compound engines are those having two cylinders of which the working lengths are the same, but the diameter of one, the **high-pressure cylinder,** is less than that of the other, the **low-pressure cylinder.** In these engines the expansion of the steam is only partially effected in the high-pressure cylinder, and on being exhausted from it, passes into an intermediate chamber which serves as a reservoir, called the *receiver*, from which the low-pressure cylinder draws its supply of steam. In the low-pressure cylinder the expansion of the steam is continued and completed; and from here it either passes into the open air or into a condenser.

2095. The chief advantage of compounding is that a greater range of expansion can be obtained than is economical in a single cylinder. With a great range of expansion there is a correspondingly great difference in the temperature of the steam from the boiler and the temperature of the exhaust. The walls of the cylinder are alternately heated by the hot steam, a part of which condenses by the process, and cooled by the exhaust. The heat taken from the cylinder walls

and carried away by the exhaust is almost a total loss. By allowing the steam to expand successively in two or more cylinders, the range in temperature in each cylinder is reduced. This reduces the quantity of steam condensed in the cylinder and the quantity of heat carried out by the exhaust.

2096. The **tandem-compound engine,** shown in Fig. 690, is one of the most common types of the stationary compound engine. In this type the high-pressure cylinder *a* is usually placed directly behind the low-pressure cylinder *b*, both pistons being connected to the same piston-rod. The exhaust of the high-pressure cylinder is carried in any

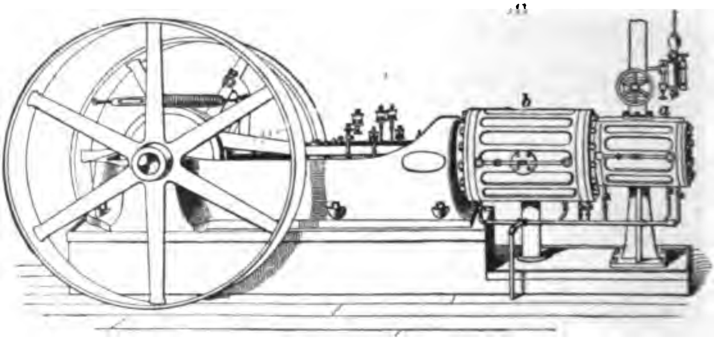

FIG. 690.

convenient manner to the low-pressure cylinder, but the more direct the conducting passages are, the better. This form of construction has one great advantage of furnishing a comparatively cheap method of compounding, as the extra cost is only a little more than that of the additional cylinder and its valve-gear. Being compact, it also takes up but very little more room than a single-cylinder engine.

2097. Cross-compound engines are those in which the two cylinders, each being in itself a complete engine, just as in the case of the duplex hoisting and haulage engines already described, are placed side by side and have their cranks connected at right angles on a common shaft. In this case, as above, the steam from the high-pressure cylinder is exhausted into a receiver or chamber from which

the low-pressure cylinder draws its steam-supply without seriously affecting the working of the steam. This class of engine has the advantage over the tandem type of running much smoother on account of the more perfect balancing of the rotating parts. It is generally used in large constructions where the tandem type would not be practicable. In compound engines, the initial steam-pressure ranges from 60 to 125 pounds per square inch, with ratios of expansion varying from 3 to 11.

2098. Triple-expansion engines are three-cylinder compound engines. In these, high initial pressures of from 120 to 250 pounds per square inch and ratios of expansion varying from 9 to 27 are used. As in the case of the compound engine, the steam passes through each of the three cylinders of the triple-expansion engine before being finally expelled. As a general rule, engines of this type are employed only where a large amount of power is required.

2099. Single-acting engines are those which take steam during only one of the two strokes of a revolution; that is, steam is admitted to the cylinder during the forward stroke of the piston, but is shut off during the return stroke.

AIR AND AIR COMPRESSION.

PNEUMATICS.

INTRODUCTION.

2100. In order to understand the various operations of tunneling, rock-drilling, pumping, mine ventilation, etc., which depend for their success upon the physical properties of air, a knowledge of the leading principles of the properties of air and gases is necessary. That branch of mechanics which treats of the physical properties of air and gases is called **Pneumatics.**

2101. The most striking feature concerning gases is that, *no matter how small the quantity may be, they will always fill the vessels which contain them.* If a bladder or football be partly filled with air, and placed under a glass jar (called a receiver), from which the air has been exhausted, the bladder or football will immediately expand, as shown in Fig. 691. The force which a gas always exerts, when confined, on the vessel which contains it, is called **tension.** The word tension in this case means pressure, and is used in this sense only in reference to gases.

FIG. 691.

NOTE.—The student who is not already familiar with the elementary properties of air should read Arts. **2153** to **2168,** at the end of this section, before proceeding further.

PNEUMATIC MACHINES.

2102. The Air-Pump.—The **air-pump** is an instrument for removing air from a given space. A section of

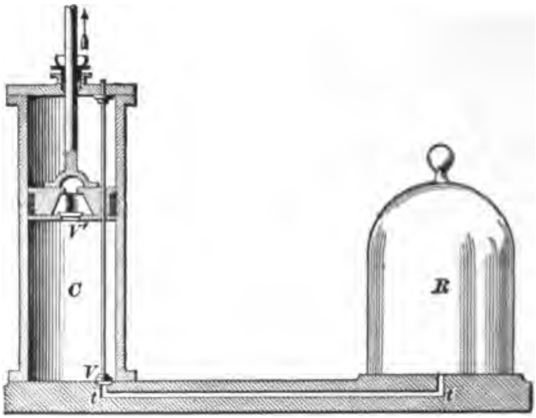

FIG. 692.

the principal parts is shown in Fig. 692, and the complete instrument in Fig. 693. The closed vessel R is called the

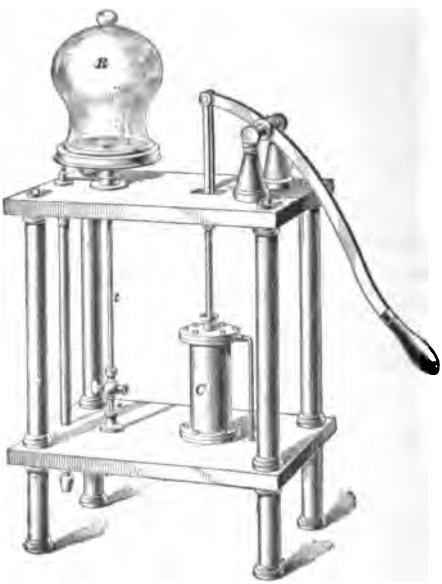

FIG. 693.

receiver, and the space which it encloses is that from which it is desired to remove the air. It is usually made of glass, and the edges are ground so as to be perfectly air-tight. When made in this form, it is called a **bell-jar receiver.** The receiver rests upon a horizontal plate, in the center of which is an opening communicating with the pump-cylinder C, by means of a bent tube t t. The pump-piston fits the cylinder

accurately, and has a valve V' opening upwards. At the junction of the tube with the cylinder is another valve V, also opening upwards. When the piston is raised, the valve V' closes, and, since no air can get into the cylinder from above, the piston leaves a vacuum behind it. The pressure upon V being now removed, the tension of the air in the receiver R causes V to rise; the air in the receiver then expands and occupies the space displaced by the piston, the space within the tube t t, and within the receiver R. The piston is now pushed down, the valve V closes, the valve V' opens, and the air in C escapes. The lower valve V is sometimes supported, as shown in Fig. 692, by a metal rod passing through the piston, and fitting it somewhat tightly. When the piston is raised or lowered, this rod moves with it. A button near the upper end of the rod confines its motion within very narrow limits, the piston sliding upon the rod during the greater part of the journey.

2103. Degrees and Limits of Exhaustion.—Suppose that the volume of R and t together is four times that of C, and that there are, say, 200 grains of air in R and t, and 50 grains in C when the piston is at the top of the cylinder. At the end of the first stroke, when the piston is again at the top, 50 grains of air in the cylinder C will have been removed, and the 200 grains in R and t will occupy the space R, t, and C. The ratio between the sum of the spaces R and t and the total space $R + t + C$ is $\frac{4}{5}$; hence, $200 \times \frac{4}{5} = 160$ grains = the weight of air in R and t after the first stroke. After the second stroke, the weight of the air in R and t would be $(200 \times \frac{4}{5}) \times \frac{4}{5} = 200 \times (\frac{4}{5})^2 = 200 \times \frac{16}{25} = 128$ grains. At the end of the third stroke the weight would be $[200 \times (\frac{4}{5})^2] \times \frac{4}{5} = 200 \times (\frac{4}{5})^3 = 200 \times \frac{64}{125} = 102.4$ grains. At the end of n strokes the weight would be $200 \times (\frac{4}{5})^n$. It is evident that *it is impossible to remove all of the air that is contained in R and t by this method.* It requires an exceedingly good air-pump to reduce the tension of the air in R to $\frac{1}{50}$ of an inch of mercury. When the air has reached this condition of rarefaction, the valve V' will not lift, and, consequently, no more air can be exhausted.

2104. Magdeburg Hemispheres.—By means of the two hemispheres shown in Fig. 694, it can be proved that the atmosphere presses upon a body equally in all directions. They were invented by Otto Von Guericke, of Magdeburg, and are called the **Magdeburg hemispheres.** One of the hemispheres is provided with a stop-cock, by which it can be screwed on an air-pump. The edges fit accurately and are well greased, so as to be air-tight. As long as the hemispheres contain air, they can be separated without trouble; but when the air in the interior is pumped out by means of an air-pump, they can be separated only with great difficulty. The force required to separate them will be equal to the area of the largest circle of the hemisphere in square inches, multiplied by 14.7 pounds. This force will be the same in whatever position the hemisphere may be held, thus proving that the pressure of air upon it is the same in all directions.

FIG. 694.

2105. The pressure of the atmosphere is very clearly shown by means of an apparatus like that illustrated in Fig. 695. Here a cylinder fitted with a piston is held in suspension by a chain. At the top of the cylinder is a plug *A*, which can be taken out. This plug is removed, the piston pushed up (the force necessary being equal to the weight of the piston and rod *B*), until it touches the cylinder-head. The plug is then screwed in, and the piston will remain at the top until a weight has been hung on the rod equal to the area of the piston, multiplied by 14.7 pounds, less the weight of the piston and rod. If a force was applied to the rod sufficiently great to force the piston downwards, it would raise any weight less than the above to the top of the cylinder. Suppose the weight to be removed, and the piston to be supported, say, midway of the

length of the cylinder. Let the plug be removed and air admitted above the piston, then screw the plug back into its place; if the piston be shoved upwards, the farther up it goes, the greater will be the force necessary to push it, on account of the compression of the air. If the piston is of large diameter, it will also require a great force to pull it out of the cylinder, as a little consideration will show. For example, let the diameter of the piston be 20 inches, the length of the cylinder 36 inches, plus the thickness of the piston, and the weight of the piston and rod 100 pounds. If the piston is in the middle of the cylinder, there will be 18 inches of space above it, and 18 inches of space below it. The area of the piston is $20^2 \times .7854 = 314.16$ square inches, and the atmospheric pressure upon it is $314.16 \times 14.7 = 4{,}618$ lb., nearly. In order to shove the piston upwards 9 inches, the pressure upon it must be twice as great, or 9,236 pounds, and to this must be added the weight of the piston and rod, or $9{,}236 + 100 = 9{,}336$ lb. The force necessary to cause the piston to move upwards 9 inches would then be $9{,}336 - 4{,}618 = 4{,}718$ lb. Now, suppose the piston to be moved downwards until it is just on the point of being pulled out of the cylinder. The volume above it will then be twice as great as before, and the pressure one-half as great, or $4{,}618 \div 2 = 2{,}309$ lb. The total upward pressure will be the pressure of the atmosphere less the weight of the piston and rod, or $4{,}618 - 100 = 4{,}518$ lb., and the force necessary to pull it downwards to this point will be $4{,}518 - 2{,}309 = 2{,}209$ lb.

FIG. 695.

2106. The Injector.—A section of an injector is shown in Fig. 696. There are many different kinds of these

instruments, but the principle is the same in all. When they are used for lifting water from a point below the discharge orifice and forcing it into the boiler of a steam-engine or locomotive, they depend for their lifting action upon the creation of a partial vacuum by the action of the steam. In the injector, Fig. 696, *F* is the connection for the steam-pipe from the boiler, *P* is the connection for the pipe from the water supply, *N* is the connection to which

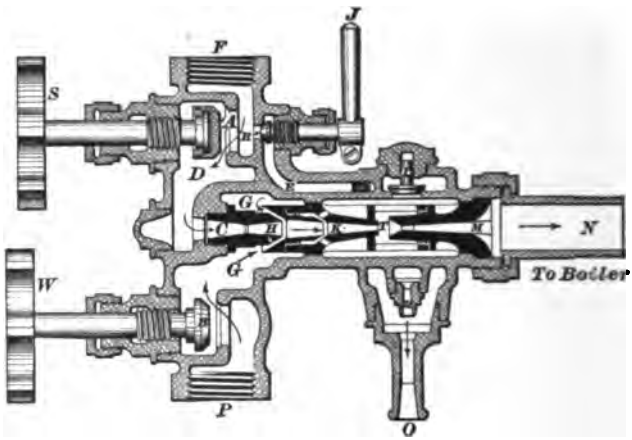

FIG. 696.

the discharge-pipe leading to the boiler is attached, and the waste water and steam are discharged through the **overflow** nozzle *O*.

2107. The method of operation is as follows: The valve *B* is first opened by turning the wheel *W*; the **primer** valve *R* is then opened by the handle *J*, thus permitting the steam to flow through the passage *E* and a connection, not shown in the figure, to the nozzle *u*. From *u* the jet of steam rushes out through *O*. A passage connects the chamber surrounding *u* with the space above valve *L*. The jet of steam from *u* out through *O* carries with it the air in the chamber to which *O* is connected, thus forming a partial vacuum in the space above *L*; the air in the passages *D*, *C*, *G*, *H*, *K*, *T*, and in the water-pipe connected at *P* is thus drawn out through the valve *L*, and a partial vacuum

is formed which permits the pressure of the atmosphere to force water through P until it finally fills the passages and flows out through L and the overflow nozzle O. As soon as water appears at O, the valve K' is closed and the main steam-valve A is opened by the wheel S, thus admitting steam to the passages C, H, K. This steam draws water from G through the opening surrounding H and discharges it through K with such a high velocity that it rushes past the opening T into the nozzle M and thence into the boiler.

THE EXPANSION OF AIR AND GASES.

2108. When a gas expands, it does work; when it is compressed, work is required to be done upon the gas to compress it. Suppose that a cubic foot of air is confined in a vessel having an area of 1 square foot and a length of 5 feet plus the thickness of the piston, so that the piston can move 5 feet. Suppose the piston to be in the position shown in Fig. 697; that the absolute pressure of the volume of air enclosed in the cylinder is 100 lb. per square inch on the piston, and that the temperature is 150°. Since the area of the piston is 1 square foot, the volume of the enclosed air is 1 cubic foot. Now, let this air expand, and keep the temperature constant by adding heat to it. The piston will move against the atmospheric pressure upon it [illegible] tance it moves; the volume of the air will increase and the pressure decrease [illegible]. When the piston has moved 1 foot [illegible] and the pressure is found [illegible] 50 lb. per square inch. [illegible] the pressure is [illegible] graphically, the effect [illegible] upon the pressure

Fig. 697.

and volume, two indefinite straight lines are drawn at right angles to each other, as $O\ Y$ and $O\ X$, in Fig. 698. Any line drawn from $O\ X$ parallel to $O\ Y$ is called an **ordinate.** Choose a convenient scale, say 1 in. = 1 cu. ft., and lay off $O\ L = 1$ in. = 1 cu. ft. of cylinder volume = the volume of

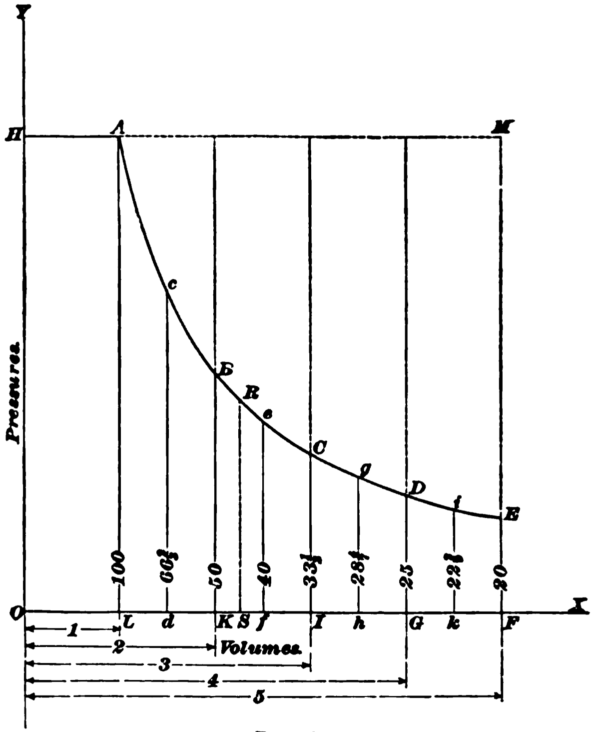

FIG. 698.

air before expanding. Make $O\ F = 5$ in. = the total volume after the piston has reached the end of the cylinder. Now, choose another scale to represent the pressures, say 1 in. = 20 lb. The length of a line representing 100 lb. would be $\frac{100}{20} = 5$ in. Lay off this distance on $O\ Y$, thus locating the point H. The pressure is 100 lb. per sq. in. throughout the distance $O\ L$; hence, drawing $H\ M$ parallel to $O\ X$, it is evident that any ordinate measured from $O\ X$ to this line, with a scale of 1 in. = 20 lb., will equal 100 lb. pressure per sq.

in. When the piston begins to move away from the position $A L$, the pressure begins to fall, and the volume to increase. The pressures corresponding to a number of different positions of the piston calculated by the formula $p_1 = \frac{p v}{v_1}$ are as follows:

When piston has moved $\frac{1}{2}$ ft., or to d, pressure = $66\frac{2}{3}$ lb.
When piston has moved 1 ft., or to K, pressure = 50 lb.
When piston has moved $1\frac{1}{2}$ ft., or to f, pressure = 40 lb.
When piston has moved 2 ft., or to I, pressure = $33\frac{1}{3}$ lb.
When piston has moved $2\frac{1}{2}$ ft., or to h, pressure = $28\frac{4}{7}$ lb.
When piston has moved 3 ft., or to G, pressure = 25 lb.
When piston has moved $3\frac{1}{2}$ ft., or to k, pressure = $22\frac{2}{9}$ lb.
When piston has moved 4 ft., or to F, pressure = 20 lb.

At the points d, K, f, I, h, G, k, F erect ordinates, and make them equal in length to the pressure at that point, drawn to the scale of 1 in. = 20 lb.; that is, make $c d = 66\frac{2}{3}$ lb., $B K$ = 50 lb., etc., and through the points A, c, B, e, C, g, D, i, E draw the curve shown in the figure. If care has been taken in drawing this figure, any ordinate drawn from a point on the line $O X$ and limited by the curve will indicate exactly the pressure of the air in the cylinder when the piston is at that point. Thus, suppose it is desired to know the pressure when the piston is at the point S. Erect the ordinate $S R$, and measure it with the same scale that was used to measure the other ordinates; the reading on the scale will be the pressure at that point.

2109. In order to find the work done by the air while the piston was traveling from L to F, and during which the pressure fell from $A L$, or 100 lb. per square in., to $E F$, or 20 lb. per sq. in., the average pressure or mean ordinate must be known. This can be found by dividing $L F$, Fig. 699, into any convenient number of equal parts; in this case, 8. Erect ordinates at the points of division, thus dividing the area $A E F L$ into 8 parts. At the middle points of the divisions, the ordinates *1–1*, *2–2*, *3–3*, etc., are drawn and measured, the lengths being marked on the drawing.

The sum of these middle ordinates is $80 + 57.1 + 44.4 + 36.4 + 30.8 + 26.7 + 23.5 + 21 = 319.9$. Then, the mean pressure $= 319.9 \div 8 = 39.99$ lb. per sq. in. Calling the mean pressure 40 lb. per sq. in., the work which the air does in expanding from L to F at a constant temperature is equal to the area of the piston in square inches, multiplied

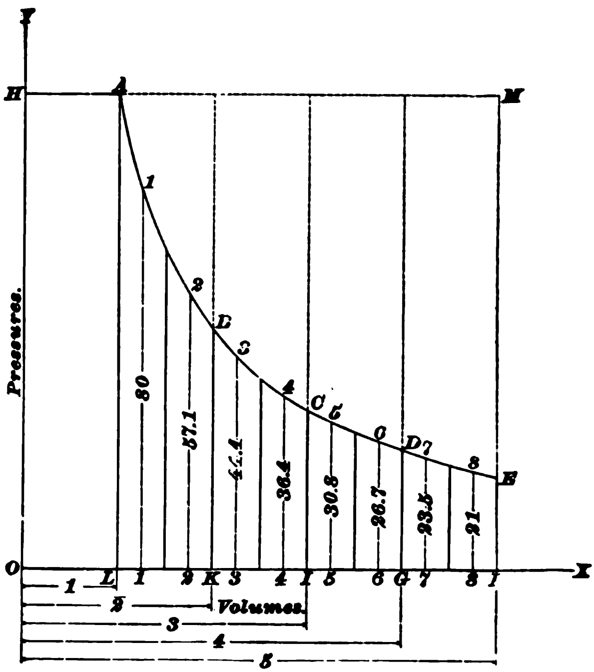

FIG. 699.

by the mean pressure per square inch, multiplied by the distance in feet through which it moves $= 144 \times 40 \times 4 = 23{,}040$ foot-pounds.

Suppose that the number of parts had been doubled; that is, that the line $L F$ had been divided into 16 equal parts, instead of 8, the sum of the ordinates drawn at the middle of these parts then would have been:

$$88.9 + 72.7 + 61.5 + 53.3 + 47.1 + 42.1 + 38.1 + 34.8 + 32 + 29.6 + 27.6 + 25.8 + 24.2 + 22.9 + 21.6 + 20.5 = 642.7.$$

$$642.7 \div 16 = 40.17 \text{ lb. per sq. in.}$$

$$144 \times 40.17 \times 4 = 23{,}138 \text{ foot-pounds, nearly.}$$

A sufficiently close result for all practical purposes can be obtained by dividing $A\,E\,F\,L$ into 10 parts.

2110. The curve shown in Fig. 698 is called the **isothermal expansion curve,** or the **expansion curve of constant temperature.** It is known in mathematics as the **equilateral hyperbola,** and, hence, when used on indicator-diagrams, is sometimes called the **hyperbolic curve of expansion.**

2111. If the air or gas were compressed, the action would be exactly the reverse of the expansion. Heat would have to be abstracted instead of added; the pressure would increase instead of decreasing, and the volume decrease instead of increasing.

In Fig. 700, let $E\,F$ represent the initial pressure = 20 lb. per sq. in., $O\,F$ the initial volume = 5 cu. ft. As the volume decreases, the pressure will increase, as indicated by the curve $E\,D\,C\,B\,A$, when the temperature is kept constant.

2112. Suppose that a volume of air expands from the same initial volume and pressure as in the case of Fig. 698, but that no heat is added or taken away; the temperature will fall; the pressure will fall much faster than in the case of isothermal expansion. If the air be compressed as in Fig. 700, and no heat is added or taken away, the temperature will rise; the pressure will increase much faster than in the case of isothermal compression. The formula which expresses this change of pressure and volume requires a table of logarithms in order to calculate the values; for this reason, the formula will not be given here. The work which the air can do when expanding under these conditions is considerably less than when it expands isothermally. In order to show this difference between the two cases, the pressures have been calculated which correspond to the

different positions of the piston in Fig. 698, and the following results were obtained:

Pressure corresponding to volume $O\ d = 56.5$ lb.
Pressure corresponding to volume $O\ K = 37.63$ lb.
Pressure corresponding to volume $O\ f = 27.47$ lb.
Pressure corresponding to volume $O\ I = 21.25$ lb.
Pressure corresponding to volume $O\ h = 17.1$ lb.
Pressure corresponding to volume $O\ G = 14.6$ lb.
Pressure corresponding to volume $O\ k = 12.0$ lb.
Pressure corresponding to volume $O\ F = 10.34$ lb.

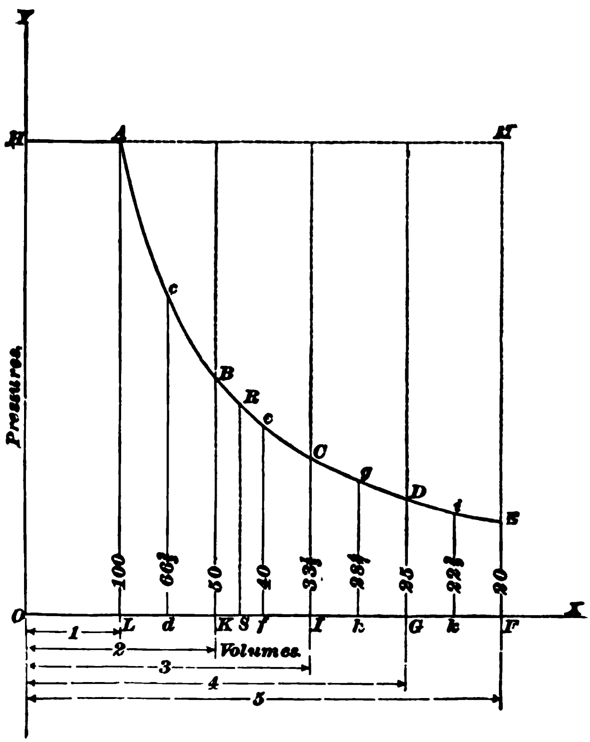

FIG. 700.

Making the different ordinates equal in length to these pressures and using the same scale as before, 1 in. = 20 lb., the curve shown in Fig. 701 is produced by tracing the

line $A\ B\ C\ D\ E$ through these points. It will be noticed that the area of $A\ E\ F\ L$, in Fig. 701, is considerably smaller than in Fig. 698; consequently, the mean pressure is less, and the work done in expanding is less. This was to be expected, since, no heat being added, the temperature must fall, and with it the pressure also. Erecting ordinates at the middle points of these divisions and measuring them

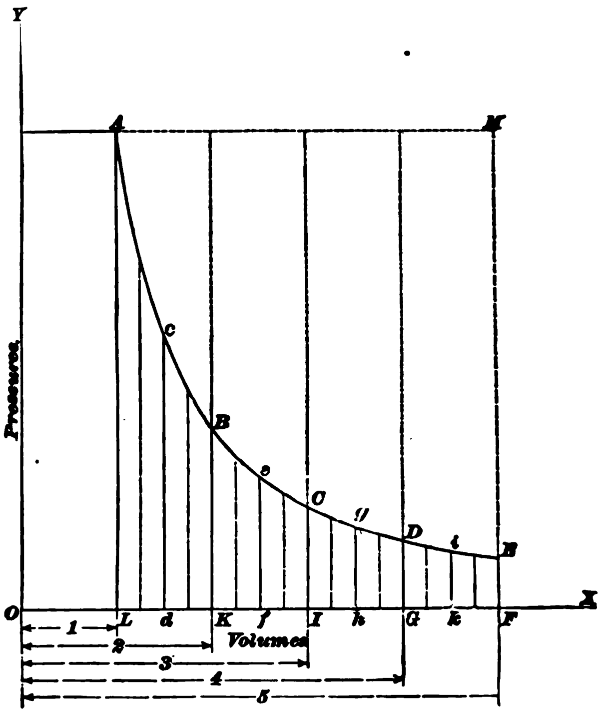

FIG. 701.

ı a manner similar to the approximate method of finding ıe mean pressure followed in Fig. 699, the mean pressure ; found to be:

$$\frac{73+45.5+31.9+24+19+15.5+13+11.1}{8}=29\tfrac{1}{8}\text{ lb. per sq. in.}$$

The work done is evidently $144 \times 29\frac{1}{8} \times 4 = 16{,}776$ ft.-lb.

2113. When a gas expands without receiving or losing ıy heat, the pressure falls as shown by Fig. 701, and it is

said to expand **adiabatically.** The curved line $A\,B\,C\,D\,E$ is called the **adiabatic curve.**

If the volume of air was 5 cu. ft., and the pressure was 10.34 lb. per sq. in.; that is, if the piston was at $E\ F$, Fig. 701, and it was compressed to 1 cu. ft., and no heat lost, the final pressure would be 100 lb. as before; the curve of pressures would be the adiabatic curve $A\ B\ C\ D\ E$, as in the case of expansion. The work which this air would do

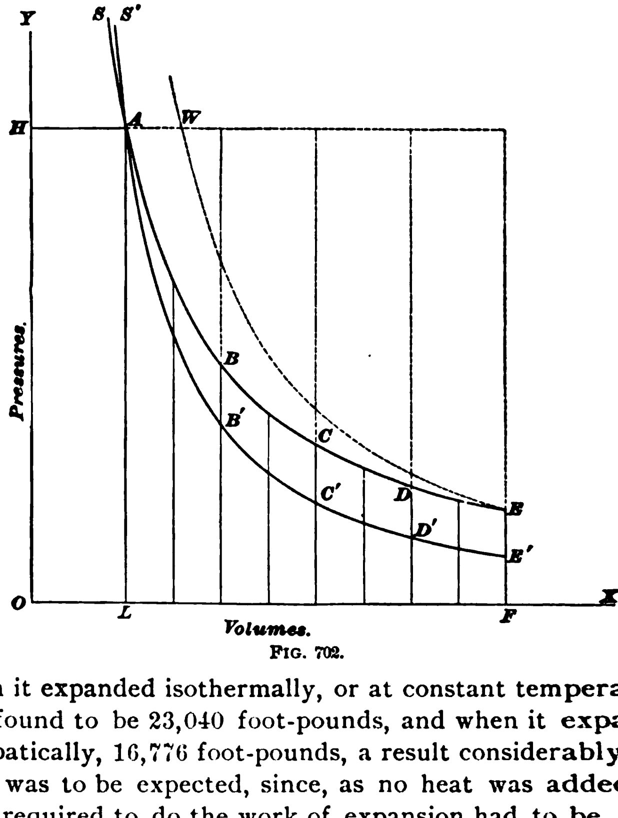

FIG. 702.

when it expanded isothermally, or at constant temperature, was found to be 23,040 foot-pounds, and when it expanded adiabatically, 16,776 foot-pounds, a result considerably less. This was to be expected, since, as no heat was added, the heat required to do the work of expansion had to be taken from the gas, thus reducing its energy and the amount of work that it could do. To better show the effects of isothermal and adiabatic expansion, the two curves shown in Figs. 698 and 701 are drawn together in Fig. 702. Here,

$S\,A\,B\,C\,D\,E$ is the isothermal curve of expansion or compression, and $S'\,A\,B'\,C'\,D'\,E'$ is the corresponding adiabatic curve. If 5 cu. ft. of air having a tension of 20 lb. per sq. in. be compressed isothermally, the curve of compression would follow the line $E\,D\,C\,B\,A\,S$, while, if compressed adiabatically, the initial tension and volume being the same, it would follow the dotted line $E\,W$. Hence, if the air was thus compressed to 1 cu. ft., it is easy to see that the work required would be far more for adiabatic compression than for isothermal compression.

2114. The mean pressure or ordinate of the adiabatic curve $A\,B'\,D'\,E'$ may be calculated directly, without drawing the curve and measuring the mean ordinates of the equal parts, by the aid of the following formula, which gives the area (A) of the space $A\,B'\,D'\,E'\,F\,L$:

$$A = \frac{p\,v - p_1\,v_1}{.41}. \qquad \textbf{(147.)}$$

Here, p and p_1 are the greater and lesser pressures, and v and v_1 their corresponding volumes. For example, the pressure corresponding to a volume of 5 cu. ft., and denoted by the ordinate $E'\,F$, was found to be 10.34 lb. per sq. in. The greater pressure was 100 lb. per sq. in. and the corresponding volume 1 cu. ft.; hence, the area $A\,B'\,C'\,D'\,E'\,F\,L$ is

$$\frac{p\,v - p_1\,v_1}{.41} = \frac{(100 \times 1) - (10.34 \times 5)}{.41} = 117.805 \text{ units.}$$

What these units are when the formula is applied to any particular figure depends upon the scale of pressures and volumes used. The mean ordinate can now be found by dividing this area by the number of cubic feet of volume represented by the length $L\,F$, in this case 4; thus, $\frac{117.805}{4} =$ 29.45125 lb. per sq. in. = mean ordinate. Since the area of the piston is 144 square inches, and as it moves 4 feet, the work it can do is $29.45125 \times 144 \times 4 = 16{,}964$ foot-pounds. The previous calculation gave 16,776 foot-pounds, a difference of 188 foot-pounds. The difference is so slight, compared

with the whole work done, that the results are practically the same.

2115. A little thought will show that the work done is directly proportional to the areas, and that the areas themselves may be considered as representing the work done on the piston during one stroke. The mean pressure was just now found to be 29.45 lb. per sq. in. Since every inch of length on any ordinate in Fig. 702 represents a pressure of 20 lb. per sq. in., the actual length in inches of the mean ordinate is $29.45 \div 20 = 1.4725$ inches. The length of the area is 4 inches, and the actual area is $1.4725 \times 4 = 5.89$ square inches. Now, if, in any diagram of this kind, the actual area be multiplied by the scale of pressures (in this case 20 lb. per in.), then, by the scale of volumes (in this case 1 in. = 1 cu. ft.), and, finally, by the area of 1 square foot in inches, or by 144 square inches, the result is the work. Hence, in this case the work $= 5.89 \times 20 \times 144 = 16{,}963$ foot-pounds, the same result as before. The work is represented by the areas, and the ratio of any two areas is the same as the ratio of the works.

2116. A study of the curves $E\,D\,C\,B\,A$ and $E\,W$ in Fig. 702 will show why the walls of air-compressors are cooled. Suppose that $E\,F$ represents a pressure of 15 lb. per sq. in., instead of 20 lb. as formerly. This is about the pressure of the atmosphere, and, consequently, the initial pressure in the air-compressor cylinder. If the air was not cooled while being compressed, the pressures corresponding to the various volumes would be given by the dotted adiabatic curve $E\,W$. The work required to compress the air to a volume of 1 cu. ft. will, of course, be far greater than that required to compress it isothermally. The cooling water tends in a measure to keep the temperature constant, so that the curve of compression follows approximately the line $E\,D\,C\,B\,A$. The extra work needed when the air is compressed adiabatically is entirely used in heating the air, which subsequently cools down to the temperature of the external air. This excess work is, therefore, entirely lost, since, when

the air cools, its pressure falls. Other things being equal, the nearer the compression curve follows the isothermal curve the more efficient is the machine.

AIR-COMPRESSORS.

INTRODUCTORY.

2117. The reasons for using compressed air are many. It can be used for driving any machine ordinarily driven by steam or water without the attending loss through condensation when steam is transmitted in long pipes, and with but a slight loss through friction, compared with that sustained by water. If the pipes are of reasonably large diameter compared with the amount of air consumed, the friction loss may be disregarded. For example, 200 cubic feet of air per minute at a pressure of 60 pounds per square inch can be transmitted through 1,000 feet of 3-inch pipe, with a loss of less than 1 pound per square inch in pressure, or through a 6-inch pipe the same distance, with a loss of less than $\frac{1}{4}$ pound per square inch. Five thousand cubic feet of air per minute at 60 pounds pressure per square inch can be transmitted through a 10-inch pipe 1,000 feet, with a loss of pressure of only $1\frac{1}{4}$ pounds per square inch.

The Lehigh and Wilkes-Barre Coal Company operate the pumps in their Nottingham shaft by means of compressed air. The air is transmitted one mile through a 12-inch pipe, the gauges indicating 45 pounds at both ends.

At the Jeddo tunnel, near Hazleton, Pa., air at 60 pounds pressure was conveyed 10,860 feet through a $5\frac{3}{4}$-inch pipe. The amount transmitted was so small, compared with the size of the pipe, that the gauges placed at both ends of the pipe indicated 60 pounds. Consequently, when deciding upon the merits of a compressed-air plant, the loss through friction may be neglected, it being only a question of the size of the pipe.

2118. The first cost of the apparatus is low compared with other methods of operating mining-tools. The air

exhausting from the drills, pumps, etc., assists in ventilating the mine. The apparatus is durable, of light weight, and occupies but little space. The air outside of the compressor from which its supply is drawn is termed **free air.** The lower the temperature of the free air, the greater will be the efficiency of the compressor. For example, suppose the temperature of the free air to be 0° F., and that a cubic foot is compressed adiabatically to 3 atmospheres gauge; its temperature will be about 225°, an increase of 225° in the temperature. If the free air at a temperature of 60° be compressed adiabatically to 3 atmospheres gauge, its temperature will be about 315°, an increase of 315° − 60° = 255°; if compressed to 3 atmospheres gauge from a temperature of 100°, its temperature after compression will be about 380°, an increase of 380° − 100° = 280°. If the air be compressed to 7 atmospheres in a manner similar to that just described, and from corresponding temperatures of the free air, the temperatures after compression will be about 380°, 490°, and 560°, respectively. The corresponding increases in temperature will be 380°, 490° − 60° = 430, and 560° − 100° = 460°. If the compression be carried farther, there will be still greater differences. It is thus plainly seen that the lower the temperature of the air when it enters the cylinder, the more efficient will be the machine.

2119. For mining purposes, few compressors condense (compress) the air to less than 3 atmospheres (44.1 pounds per square inch) gauge pressure, or exceed 7 atmospheres (102.9 pounds per square inch) gauge pressure. As was shown in the preceding pages, air becomes heated when compressed, and the pressure increases very rapidly. If no means are provided for cooling the air while being compressed, so that it will be kept at, as nearly as possible, the same temperature it had on entering the cylinder, the curve of compression will follow the adiabatic curve. When the compressed air is used near the point where the compressor is situated, it occasions no particular loss; but when the compressor is situated a thousand feet or more from the

point where the air is used, and the air has to be transmitted to that point through 1,000 feet or more of pipe, it cools down to the temperature of the outside air; its pressure falls in consequence of this loss of heat, and there is a very considerable loss of power. Add to this the friction of the engine and compressor, a slight loss through friction of the air in the pipe, and the loss through leakage; the result is that, even when the air has been cooled to a greater or less extent, according to the type of compressor, the efficiency averages about 50%, being above that in some plants and below in others. By *efficiency* is meant the ratio of the work obtained from the air to the work done in compressing it. The first can be obtained when the pressure and amount of air used in a given time is known, and the last is found from the indicator-card of the steam-engine, or by other means if some other motor is used. Thus, suppose that the indicated horsepower of the steam-cylinder is 23.45 and the power obtained from the compressed air is 13.8 horsepower, the efficiency would be $\frac{13.8}{23.45} = .5885$, or 58.85%.

Unless the air is cooled during compression, or some other device (to be described farther on) is employed, the efficiency will fall below the 50% average given above.

TYPES OF AIR-COMPRESSORS.

WET COMPRESSORS.

2120. There are two systems in use by which it is attempted to absorb the heat developed during compression. They are so different in their methods of cooling and in the results obtained that it is usual to make two distinct classes of them, viz., *wet compressors* and *dry compressors*.

2121. A **wet compressor** is one in which the water is introduced directly into the air-cylinder, and thus brought into contact with the air. It is made in two forms; in one, the water is injected into the cylinder in the form of a finely divided spray, thus mixing thoroughly with the air; in the

other form, the cylinder is filled with water on both sides of the piston, the air being admitted above the water, and is compressed by the water rather than by the piston.

2122. In Fig. 703 is shown a **Dubois & Francois high-speed double-acting water-injection air-compressor.** In order to more clearly show the valve arrangements, etc., a section of the air-cylinder only is given. The piston-rod *R* is connected at its other end to the piston of a

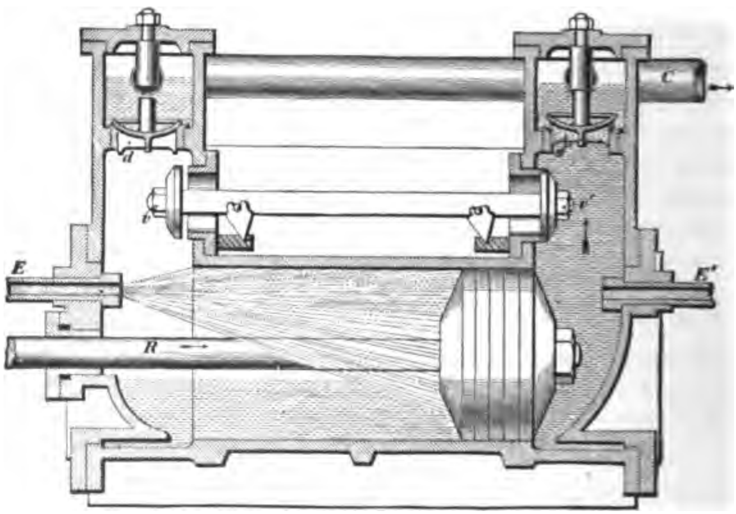

FIG. 703.

steam-engine, which affords the power needed for the compression. Let the piston be moving in the direction of the arrow. The valve *v* is open, and the air is following the piston during the stroke. The water is being injected through the two inlets *E* and *E'*. On the right-hand side of the piston, the water is being shoved upwards to fill the clearance space between the piston and the discharge-valve *d'*; the air which occupied this space is compressed, and keeps the inlet-valve *v'* against its seat. When the air reaches a certain pressure, which can be fixed to suit the purpose for which the air is to be used, the discharge-valve

d' is raised, and the air passes out and is discharged through the delivery-pipe C into a conduit. Any excess of water is also discharged through the valve d' into the conduit, but is collected and forced back into the cylinder through the nozzles E and E'.

Suppose the piston to be on the return stroke. The valve d' falls; the weight of the water causes it to fall and follow up the piston, leaving a vacuum behind it. The pressure of the atmosphere against the left side of the valve v' forces it to the right, and, with it, the valve v against its seat. The air then flows in and follows up the piston on the right side and is compressed on the left side, the operation being repeated exactly as before described. It will be noticed that both discharge-valves open into the same delivery-pipe C. This is called a **double-acting compressor,** because the air is compressed on both sides of the piston, that is, twice during each revolution of the crank-pin.

2123. In Fig. 704 is shown an elevation and section through the air-cylinder of a **Burleigh single-acting vertical air-compressor.** Only one cylinder is seen in the cut, but there are two more behind the one shown—an air-cylinder, and a steam-cylinder to drive the compressor. The cranks of the air-cylinders are set directly opposite each other, so that they are on the opposite dead-points at the same instant. The air is compressed during the upward stroke, and admitted during the downward stroke. The piston has a large valve V in it which is raised during the downward stroke, allowing the free air to enter and fill the cylinder; at the same time, water is injected through the pipe S. The water is not sprayed in during compression, as in the compressor previously described. It nearly fills the clearance space, and cools the air somewhat by reason of cooling the cylinder walls and compelling the air to come into contact with it when resting on top of the piston during the up stroke. The discharge-valve d is raised when the pressure reaches the desired point, the air passing out through the delivery-pipe C.

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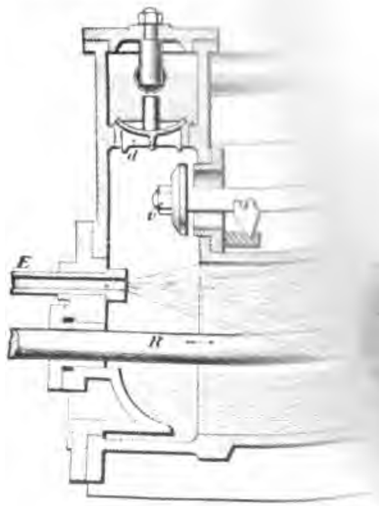

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2124. In direct-acting air-compressors where the air-cylinder is behind the steam-cylinder, and both air-piston and steam-piston are connected to the same rod, the point of greatest compression is the point where the steam pressure is nearing its lowest point, unless there is no cut-off, and the steam follows the piston for the full stroke at initial pressure. This, however, is very wasteful of steam, and with a single steam and air cylinder in line, the compressor requires a heavy fly-wheel in order to have a cut-off. In the Burleigh compressor, the crank of the steam-cylinder is so set that when the cranks of the air-cylinder are on their dead-points, the steam-piston will have advanced only about $\frac{1}{8}$ of its stroke. The steam-cylinder is, of course, double-acting, and by this arrangement the full steam pressure acts upon the air-piston at the point of greatest compression.

2125. Another type of the wet compressor is shown in Fig. 705. The water surrounds the piston on both sides and partly fills the chambers above. Suppose the piston to

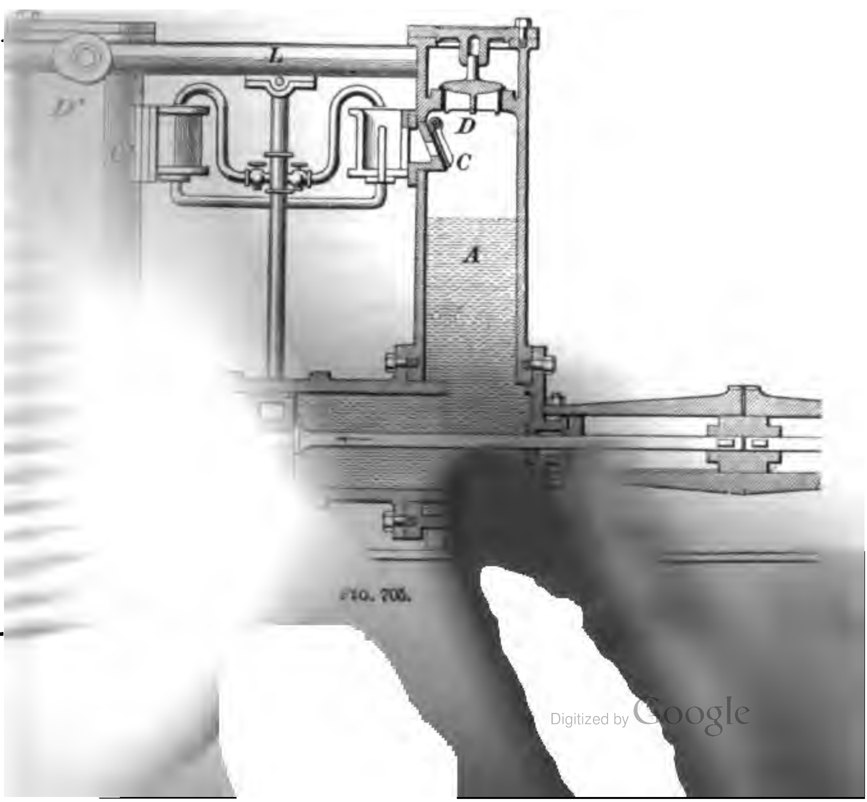


FIG. 705.

be moving to the left; the water in the chamber *A* falls, following the piston, and leaves a vacuum behind it. The pressure of the free air causes the valve *C* to open, and the chamber *A* is thus filled with air at atmospheric pressure. In the mean time, the air in *B* is compressed, and when the desired pressure is reached, the valve at *D'* (similar to *D*) is raised, and the air is discharged into the delivery-pipe *L*. When the piston begins its return stroke, the pressure of the air in the delivery-pipe causes the valve *D'* to close; the inlet-valve at *C'* opens, and the foregoing process is repeated. The chambers *A* and *B*, the valves *C* and *C'*, and also the valves *D* and *D'*, are exactly alike.

2126. The type of air-compressor last described is much inferior to the water-injection type. It has all of the disadvantages of the wet-compressor class, and, in addition, it will not deliver as cool air as a compressor in which the water is injected in the form of a fine spray and thoroughly mixed with the air. The following are the principal objections to the wet-compressor class:

I. The impurities in the water. The water may be strongly acid or strongly alkaline, and act chemically upon the metal surfaces, thus gradually destroying them. It may contain dirt and grit, and thus wear out the cylinders, pistons, packing, etc., very rapidly.

II. The water renders lubrication difficult, owing to the fact that oil floats on its surface. This also increases the wear of the parts.

III. The water absorbs a considerable portion of the compressed air, which is, of course, entirely lost.

IV. There is a loss of power, owing to the inertia of the water, the engine being required to put it in motion and bring it to rest during every stroke.

V. The speed of the compressor is limited to that of a water-pump, the average piston speed of which is about 100 feet per minute.

VI. The greatest objection is that, when the wet air is used expansively, the moisture freezes in the cylinder and

exhaust-pipes, owing to the temperature of the expanding air falling many degrees below zero. The ice collects, and in many cases stops the engine. This last objection has been almost eliminated, owing to the means employed to rid the air of its moisture when in the receiver.

2127. The arguments in favor of the wet compressor, particularly of the injection type, are that the air is compressed nearly isothermally, and there is no loss, owing to the large clearance space between the piston and the valves when the piston is at the end of its stroke. Diagrams taken from the cylinders of a wet compressor of the injection type gave the following results: The work expended in compressing 10.76 cubic feet of air to 4.21 atmospheres was 38,128 foot-pounds. Compressed isothermally, the work would have been 37,534 foot-pounds, the difference being 594 foot-pounds, or a loss of 1.6%. Compressed adiabatically, the work would have been 48,158 foot-pounds. The temperature of the air on entering the cylinder was 50° F., and, on leaving, 62° F., an increase of only 12° F. Had the air not been cooled, the resulting temperature would have been 352° F., and the increase, $352° - 50° = 302°$ F.

DRY COMPRESSORS.

2128. In Fig. 706 is shown a **Clayton double-acting water-jacketed air-compressor.** The steam and air cylinders are in line with each other, but are situated on opposite ends of the bed-plate, with the crank-shaft and fly-wheel between them. The peculiar construction of the cross-head permits this. The two parts *C*, *C* of the cross-head are joined by two strong rods *D*, of which only the upper one is visible. The bottom of the bed is planed, and the cross-head slides upon it as a guide. *H* is the air-delivery pipe. The object of placing the fly-wheel in the center, and having the two cylinders opposite each other, instead of tandem, or one behind the other, is to economize room.

A section of the air-cylinder is shown in Fig. 707. Suppose the piston to be moving in the direction indicated by the arrow. The suction-valves (inlet-valves) D', which open inwards, are forced to their seats by the pressure of the air in front of them, and the discharge-valves F' are forced open for the same reason, when the air reaches the desired pressure, which is determined by the tension of the springs at E'. The air follows the arrows and discharges through H, being prevented from entering the other end of the cylinder by reason of the spring E pressing the valves F to

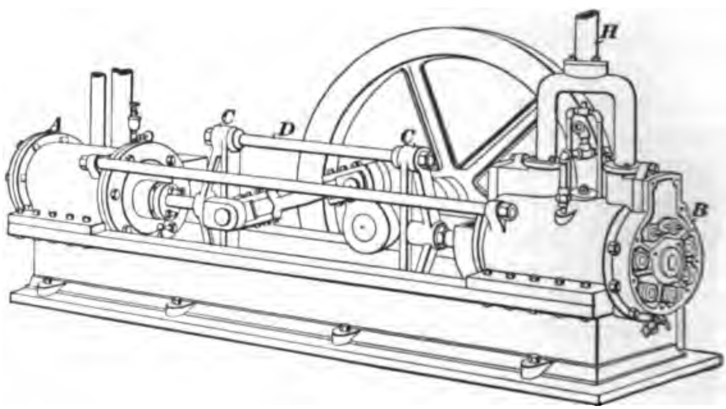


FIG. 706.

their seats. While the piston has been moving as described and leaving a vacuum behind it, the atmospheric air has forced open the valves D against the resistance of the springs C, allowing the free air to enter the cylinder. At the instant that the piston reaches the end of its stroke, the springs C draw the valves D to their seats and prevent the air retained in the cylinder from passing out. The process is again repeated, the discharge being through the valves F in the left-hand end of the cylinder.

This illustration also shows the manner of cooling the air; the walls of the cylinder are hollow, and the water enters through the U-shaped pipe $K' K$ (see also Fig. 706), flowing around the cylinder until it finally passes out through the water-delivery pipe L. The cold water cools the cylinder

walls, which, in turn, cool the air. This method of cooling

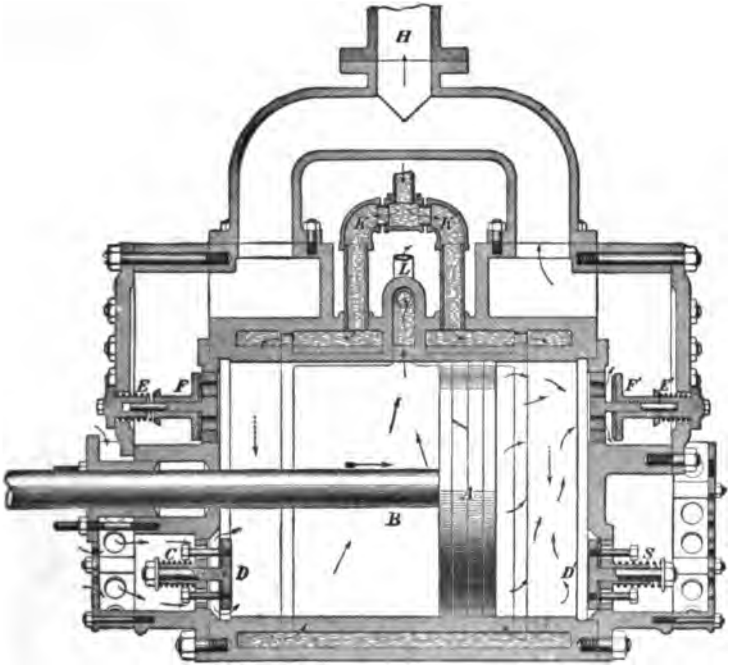


FIG. 707.

by having the water circulate around the hollow cylinder walls is termed a **water-jacket.**

2129. The clearance space has been mentioned several times in the preceding pages, as if it exerted a prejudicial effect upon the working of the compressor. To show the effect which it really produces, assume that the air has been compressed isothermally. In this case, there would be a certain loss of power, owing to heat having been produced and then absorbed by the cooling methods employed. As part of the air was not discharged, the work required to heat this air has been lost. Had the air been compressed adiabatically, the extra heat due to compression retained by the air in the clearance space is given up during the return stroke, and assists in the work of compression. The best

air-compressors give results midway between the isothermal and adiabatic compression, and when the clearance space is not excessive, the loss due to it is so small that it may be practically neglected.

2130. A section of the air-cylinder of a compressor in which the clearance is reduced to a very small amount is shown in Fig. 708. This is an **Ingersoll-Sergeant piston-inlet compressor.** The piston is cast hollow, the rod

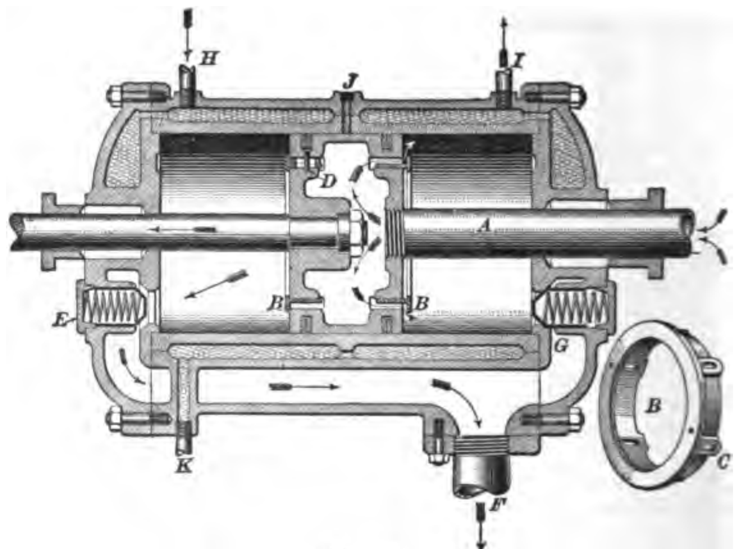


FIG. 708.

being fastened to it by means of a nut, as shown. A tube *A*, of such length that, when the piston is at the left-hand end of its stroke, its end will project through the stuffing-box on the right-hand side, is screwed into the right-hand side of the piston. The atmospheric air communicates with the hollow space in the piston by means of the tube *A*, as shown in the figure. On both sides of the piston is a ring *B* (shown in perspective at the right-hand side of the section). It will be noticed that the ring has an extension in the form of a hollow cylinder on which are lugs *C* having oblong holes. On the piston itself are taper pins *D*, which fit loosely in the

holes of the lugs, so that a slight forward or backward movement of the ring can be obtained. These rings form the inlet-valves, and operate as follows: Suppose that the piston is moving in the direction indicated by the arrow on the piston-rod. The right-hand side valve *B* is open; the left-hand side valve *B* is closed by reason of the pressure of the compressed air acting against it. The free air enters the piston through the tube *A*, and flows out through the right-hand side inlet-valve *B* into the cylinder. When the proper pressure has been reached, the delivery-valve *E* opens, and the air is discharged, following the direction indicated by the arrows, out through the pipe *F*. When the piston reaches the end of its stroke, and reverses, the valves *B* tend to continue in the former direction, according to Newton's first law of motion; hence, their inertia causes the right-hand valve to be thrown against its seat, and the left-hand valve to open. The operation above described is again repeated, except that the free air now flows through the left-hand inlet-valve, and the compressed air is discharged through *G*.

The air is cooled by means of a water-jacket, the walls being hollow and the water flowing around them, entering through *H* and flowing out through *I*. *K* is a drain-pipe supplied with a valve, and is for the purpose of draining the water from the cylinder. As there are no suction-valves in the ends of the cylinder, the greater part of the cylinder-heads is also water-jacketed. Oil drops through the small orifice *J*, and lubricates the cylinder. The clearance is reduced to a very small fraction of the cylinder volume, and the compressor can be run at as high a speed as desired.

DUPLEX COMPRESSORS.

2131. With the exception of the Burleigh, all of the compressors previously described have been what are termed **straight-line compressors**; that is, the center lines of the steam and air cylinders have formed one straight line. When two straight-line air-compressors are placed side by side, having a common crank-shaft, they are called **duplex**

compressors. The cranks of this type are set at right angles, and the distribution of the power may be understood from Figs. 709 and 710. In Fig. 709, *A* and *B* are the

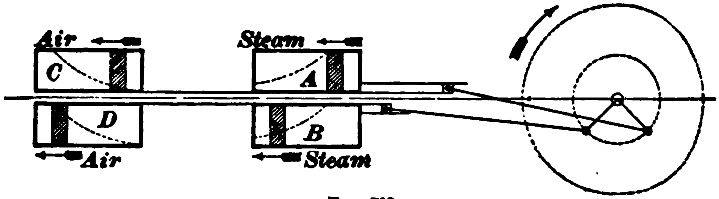


FIG. 709.

steam-cylinders, and *C* and *D* are the air-cylinders. The larger dotted circle represents the fly-wheel, and the smaller one the path of the crank-pin. The cylinder *A* has the full steam pressure on its piston; as but little power is needed in *C* at this point, the greater part of the work is transmitted through the shaft to the piston in *B*, and from thence to the air-piston *D*, where the compression has now reached its highest point. In the cylinder *B*, the steam has expanded until it is very near its terminal pressure, as indicated by the dotted expansion line. In *C*, the compression is just beginning.

In Fig. 710, the two cranks of the last figure are imagined to have turned through a quarter of a revolution. The con-

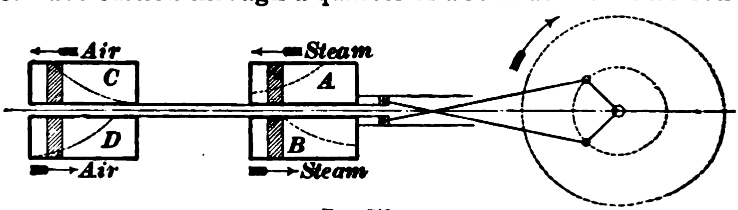


FIG. 710.

ditions are now reversed. The stroke is being completed in *A*, and just beginning in *B*; the air has reached the point of highest compression in *C*, and the compression is just beginning in *D*. The greater part of the work in *B* is now transferred to *C*. It will be seen from this, that the steam acts principally to drive the air-piston of the cylinder diagonally opposite to it.

2132. An illustration of a light **duplex compressor** made by the Rand Drill Co. is shown in Fig. 711. It is so made that it can easily be taken apart and transported on

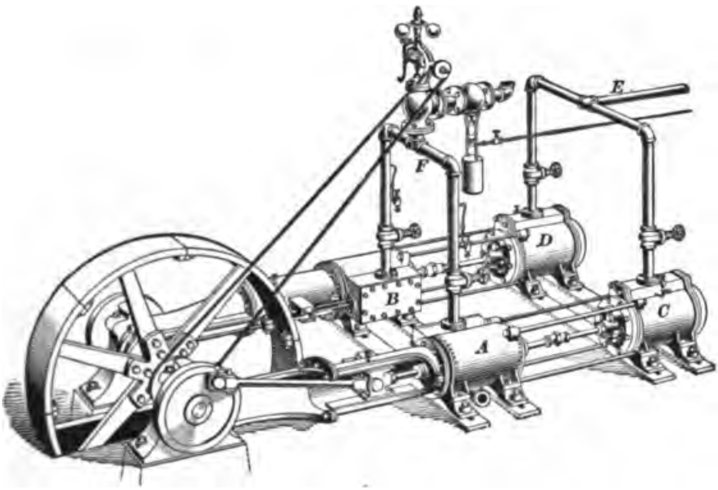


FIG. 711.

muleback. *A* and *B* are the steam-cylinders, and *C* and *D* are the air-cylinders. *E* is the air-delivery pipe, and *F* is the steam-pipe.

2133. Some of the advantages of the duplex type are the following: Since the cranks are set at right angles, the engine can not get on its dead-center. One cylinder can be detached from the other when only half the capacity of the machine is required. The power and resistance being equalized through opposite cylinders, large fly-wheels are not necessary.

2134. Some of the disadvantages are: The strains are indirect, angular, and intermittent. It is necessary, therefore, to greatly increase the strength of parts, to add a crank of increased diameter with larger bearings, and to build very much stronger foundations, since excessive strains will be brought upon the bearings should the foundations settle at any point, resulting in friction and liability to

breakage. The friction loss in the duplex type is seldom less than 15% of the indicated horsepower of the engine, while in the straight-line type it is sometimes as low as 5%.

COMPOUND COMPRESSORS.

2135. When very high pressures are desired, compound air-compressors should be used. In these machines the air is compressed usually to about 30 pounds in the first cylinder, and then delivered into the other cylinder, where it is compressed to any desired extent.

2136. A compound air-compressor built by the Norwalk Iron Works is shown in Fig. 712. *A* is the low-pressure cylinder, into which the free air is taken. *B* is the

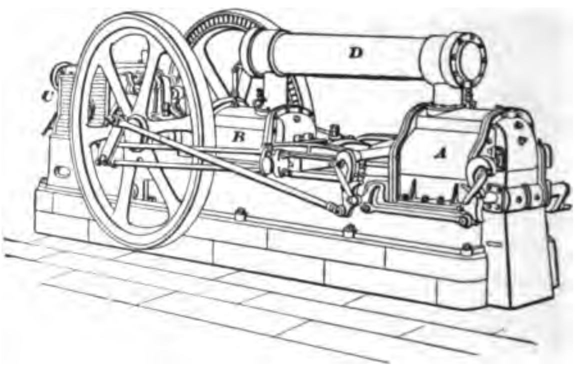


FIG. 712.

high-pressure cylinder, and *C* is the steam-cylinder, all three being in line. The two air-cylinders are water-jacketed. The air is first compressed to 30 pounds per square inch in *A*, and is then discharged through the large pipe *D*, called the inter-cooler, into *B*, where it is compressed to the required pressure. The pipe, or inter-cooler, *D* is also water-jacketed, so as to cool the air and get it into the high-pressure cylinder at as low a temperature as possible. The valves are operated by means of cams and levers, an arrangement in many respects superior to the poppet or spring valves of the previously described compressors. The inter-cooler effects quite a saving in power, this saving being

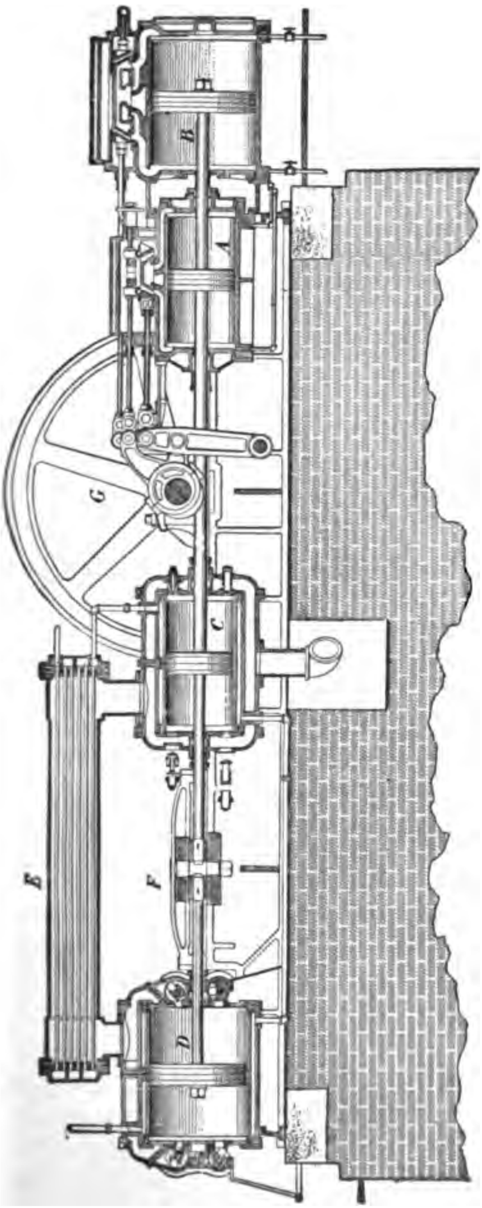


FIG. 713.

dependent upon the temperature of the air when entering the high-pressure cylinder, and also upon the ratio of the volume of the inter-cooler and clearance space outside of the discharge-valve to that of the low-pressure cylinder. The principal advantage of the compound air-compressor lies in the reduction of the clearance-space and in the equalizing of the stresses on the engine. By means of the compound air-cylinders, a pressure of 5,000 pounds per square inch can be obtained. To obtain such a high pressure as this in a single cylinder would require a very long stroke, and the loss due to clearance would be excessive.

2137. In Fig. 713 is shown a section of a compound air-compressor

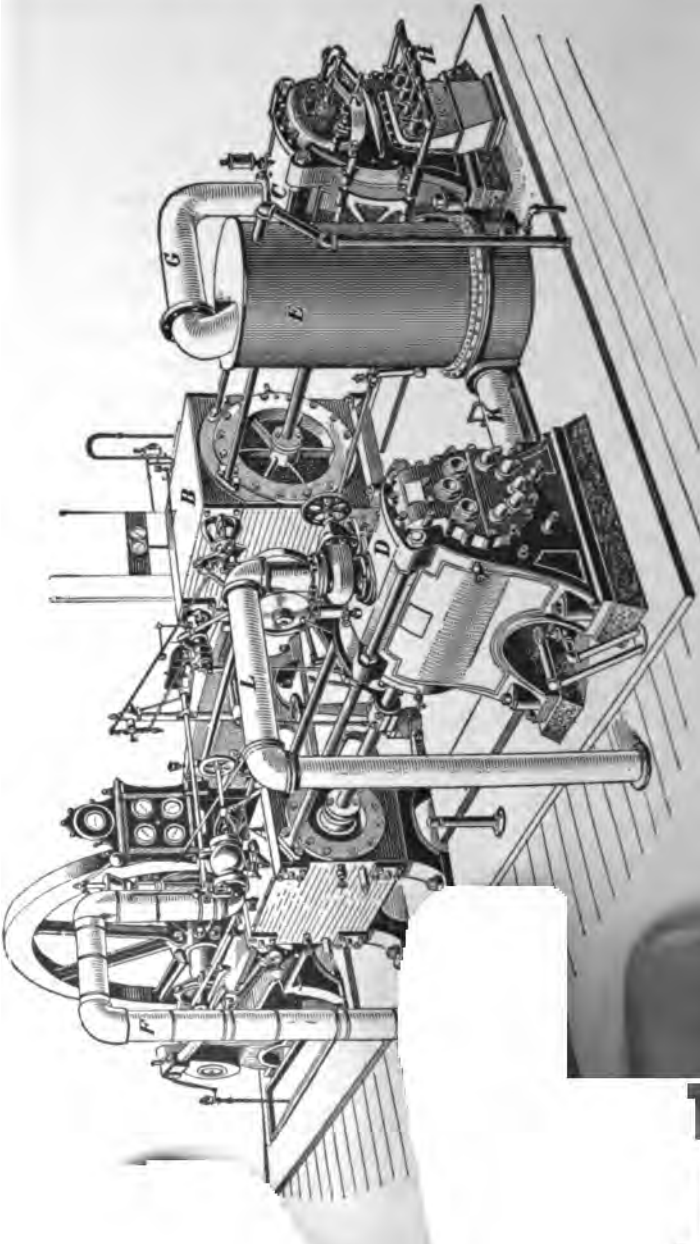


Fig. 714.

built by the same company, which differs from the other, from the fact that it is driven by a tandem-compound steam-engine. All four cylinders are in the same straight line. *A* is the high and *B* the low pressure steam-cylinder; *C* and *D* are the corresponding air-cylinders. *E* is the inter-cooler, which is partly filled with pipes through which the cold cooling water circulates. These pipes divide the air-current into small streams, and enable nearly every particle to come into contact with the cold surface, thus reducing the temperature very rapidly. *F* is the cross-head, and *G* one of the two fly-wheels. In this compressor, all of the advantages are obtained that are characteristic of the tandem-compound type of engine, together with those to be derived from the compound compressor previously described; in other words, the consumption of steam is reduced, and the strains are far more equally distributed throughout the stroke.

2138. A **Rand duplex-compound air-compressor** driven by a **Corliss cross-compound condensing steam-engine** is shown in Fig. 714. *A* and *B* are the high and low pressure steam-cylinders, *F* being the steam-pipe; *C* is the low-pressure air-cylinder. Air enters each end of the cylinder alternately. The inlet-valves *H* are actuated positively by a combination of levers and yokes, no springs being used. The air is here compressed to almost 30 pounds, and then discharged through the pipe *G* into the inter-cooler *E*, where the temperature is reduced by means of coiled pipes through which cold water circulates. From the inter-cooler, the air is conducted through the pipe *K* into the high-pressure cylinder *D*, where it is further compressed to the required pressure and discharged through the [illegible] into the receiver.

2139. [illegible] shows a plan and side elevation of a [illegible]lex air-[illegible]r driven by water. The fly-wheel *F* lar[illegible] of cup-shaped projections on its rim. te[illegible]cted to the wheel by the pipe *A*, dis- [illegible]elocity and striking the cup-shaped

vanes, thus causing the wheel *F* to turn. The wheel imparts its motion to the cross-head and piston by means of the connecting-rod *B*, thus compressing the air. These machines have a high efficiency when properly designed, and are very simple in their construction. Where a natural head of water, say of 50 feet or more, is available, they can be used to a great advantage.

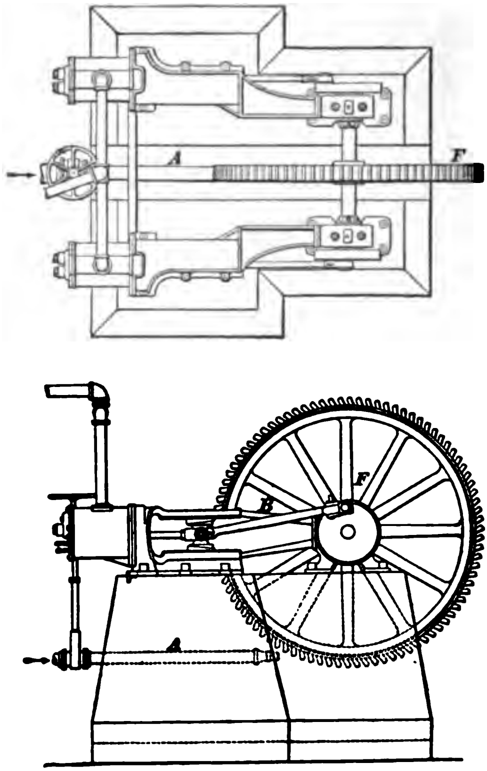


FIG. 715.

RECEIVERS.

2140. In all cases governing the use of compressed air, there should be a **receiver** placed within at least fifty feet of the compressor. The receiver acts not only as a reservoir, but also corrects the irregularity of air admission from

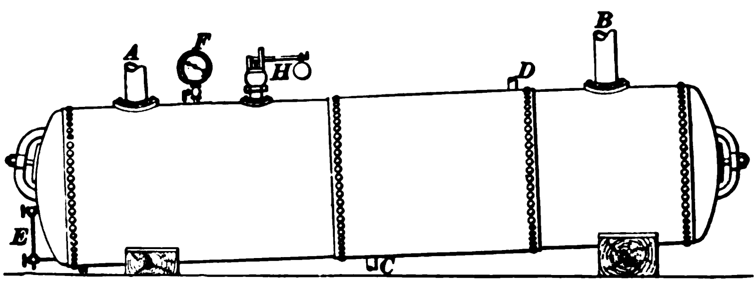


FIG. 716.

the compression-cylinder, and delivers it to the hoist, pump, or drill with great regularity of pressure, in much the same manner that a boiler delivers steam to an engine. In designing receivers, when the compressed air is to be used for driving rock-drills, it is customary to allow about ten cubic feet of receiver-volume for each drill; i. e., for five drills, the volume of the receiver would be about 50 cubic feet. In all cases, the larger the receiver, the better.

2141. In Fig. 716 is shown a **horizontal air-receiver,** and in Fig. 717 a **vertical air-receiver.** The air enters

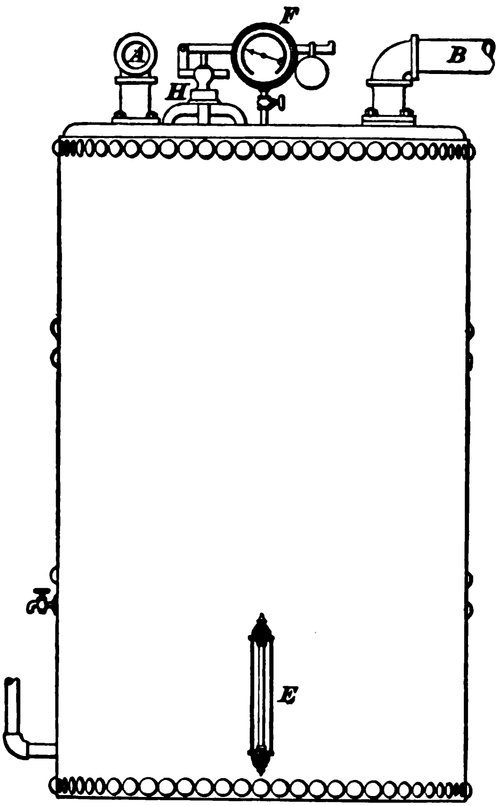


FIG. 717.

the receiver at A, flows through a series of pipe-coils, and

discharges through *B*. These pipe-coils are constantly surrounded by water flowing through them; this cools the air and dries it at the same time, the moisture dropping to the bottom of the coils. The glass gauge *E* indicates the amount of moisture deposited, and when it gets higher than desired, it is drained off. The cooling water enters at *C* and is discharged at *D*. *F* is a gauge to show the pressure of the air, and *H* is a safety-valve to prevent the pressure from becoming too high and making the receiver dangerous through liability to blow up.

PRESSURE-REGULATORS.

2142. In addition to a receiver, an air-compressor should be provided with a **pressure-regulator.** The pressure-regulator is to an air-compressor what a governor is to a steam-engine. Fig. 718 shows a regulator manufactured by the makers of the Norwalk compressors. It is placed on the steam-supply pipe of the steam-cylinder, and its function is to reduce the amount of steam admitted to the engine cylinder when the air pressure reaches a fixed limit in the receiver, and to admit more steam when the consumption of the compressed air has increased to such an extent that the pressure in the receiver is lowered. The less steam admitted, the slower the engine speed, and, consequently, the less the amount of air compressed; the more steam admitted, the greater the engine speed and the greater the amount of air compressed. Hence, the amount of air compressed per minute is varied by varying the speed of the compressor.

FIG. 718.

In the figure, *A* is the body of a balanced globe-valve; that is, the pressure is the same on all sides of the valve, and a very slight force only is required to move it up or

down. Above the valve is a small cylinder *B*, having a piston connected to the valve below by the stem *C*. At the side of this cylinder is a small spring safety-valve *D*, the under side of which connects with the receiver by a pipe. The hand-wheel *E* varies the tension of the spring so that the pressure in the receiver can be adjusted as desired. When the pressure in the receiver has reached the desired limit, the safety-valve *D* allows the air to escape and pass into the small cylinder *B*, beneath the piston; if no escape was provided, the piston would be driven to the top of the cylinder, the valve in *A* would be held to its seat, and the engine stopped. To prevent this, a very fine slot is cut in the side of the small cylinder *B*. When the piston rises, it uncovers this slot, and thus furnishes an escape for the air which is passing the safety-valve. If only a little air passes the valve, a small part of the slot will accommodate it, and the piston will take a low position, the speed of the engine being then but slightly reduced. If more air escapes, the piston will rise higher, in order to allow more of the slot to be uncovered, and thus provide a larger opening for the exit of the air, the engine speed being still further reduced. That the engine may be prevented from entirely stopping, a screw-stop *F* is placed on the top of the cylinder *B*; this prevents the valve in *A* from closing more than is sufficient to run the engine at the slowest speed that will carry it over the dead-centers.

INDICATOR-CARDS.

2143. In Fig. 719 are shown two indicator-cards, one taken from the steam-cylinder and the other from the air-cylinder. The most striking characteristic of these cards is that the pressure of the discharged air is considerably higher than the initial pressure of the steam. The area of the two cards is very nearly the same, that of the air card being a little less; this shows that the work done in both cylinders is practically the same, the extra work shown by the steam card being used to overcome the engine friction. The extra energy of the steam in the first half of the stroke where

it overcomes but a slight resistance is stored in the fly-wheel and reciprocating parts, and given out when needed at the end of the stroke. The reason that the upper line of the air card is wavy instead of being straight is that the discharge-valve has a constant tendency to close, and is held open only by the pressure of the air in front of it. This varies somewhat towards the end of the stroke, and causes the valve to have a slight to-and-fro movement, which produces the wavy line. If the valve were worked in such a manner that it could open at only one point and be closed at another, like the valves of an engine-cylinder, the line

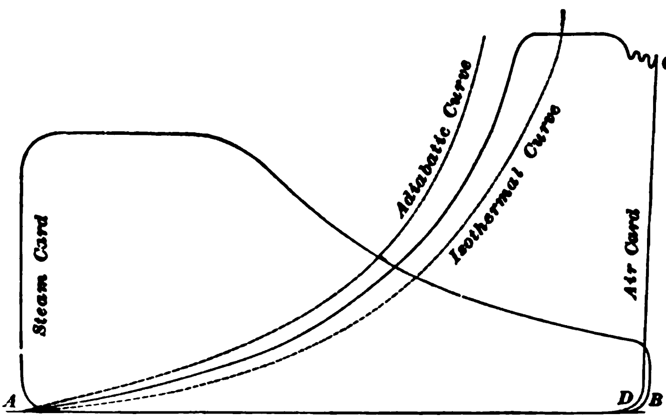


FIG. 719.

would be straight. The card also shows that the line CD is very nearly perpendicular to the atmospheric line AB, and also that it is practically straight. This indicates that the clearance is very small, since, if there were air of a high pressure behind the piston when it began the return stroke, it would expand and cause the line CD to curve, corresponding to the compression-line of a steam-engine cylinder diagram. This effect is illustrated in Fig. 720. The two dotted lines in Fig. 719 are the adiabatic and isothermal compression-curves, the actual compression-line falling about half way between them, owing to the water-jacket. These air diagrams serve not only to show the work actually needed in the air-cylinder, but also to determine the volume

of the free air actually compressed. Theoretically, this volume is equal to the area of the piston, multiplied by the length of the stroke. Actually, however, owing to imperfections in workmanship, the air does not begin to compress at the instant the piston begins its stroke. The point where the compression begins is indicated on the diagram by the point A, where the compression-curve begins to leave the atmospheric line $B\,C$. The length of the stroke is proportional to the length of the atmospheric line $B\,C$. The ratio

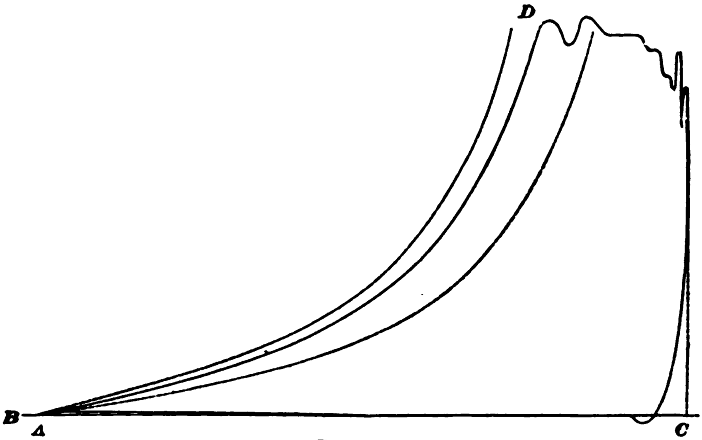


FIG. 720.

of the lengths of $B\,A$ to $B\,C$ will give the percentage of theoretical volume lost. In this case, $\frac{B\,A}{B\,C} = .034$, nearly, $= 3.4\%$.

REHEATING COMPRESSED AIR.

2144. Air can, of course, be expanded exactly like steam when used as a motive power, and the gain through expansion is nearly as great as in the case of steam. The chief difficulty lies in the intense cold produced by air, at a high pressure and normal temperature, expanding down to the pressure of the atmosphere. Thus, if a cubic foot of air at a temperature of 60° and a pressure of 88.2 pounds be expanded adiabatically, performing work, to the pressure of the atmosphere, the resulting temperature will be 151° below

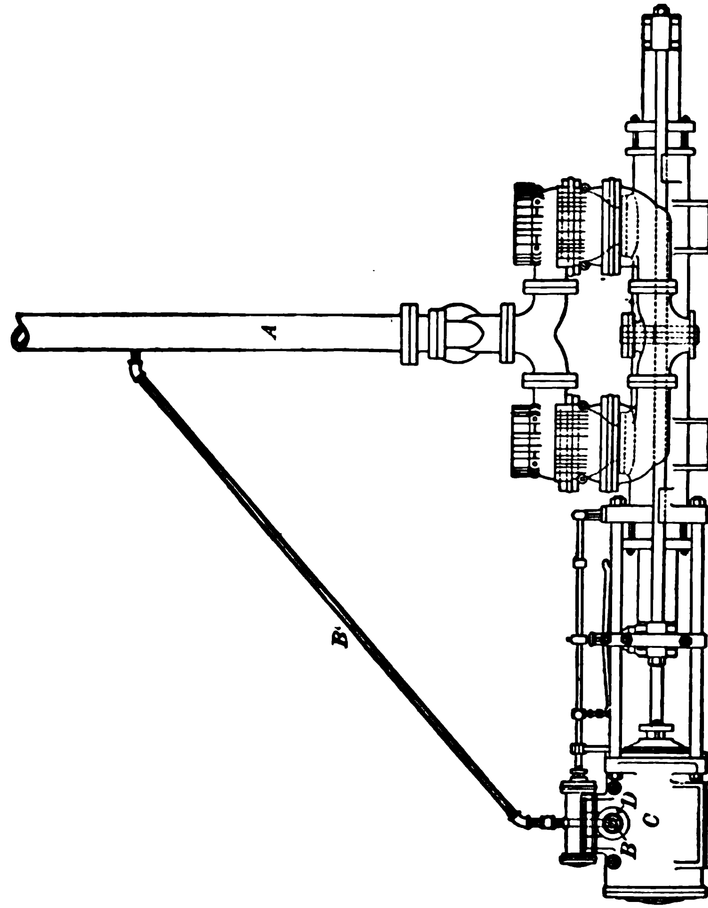
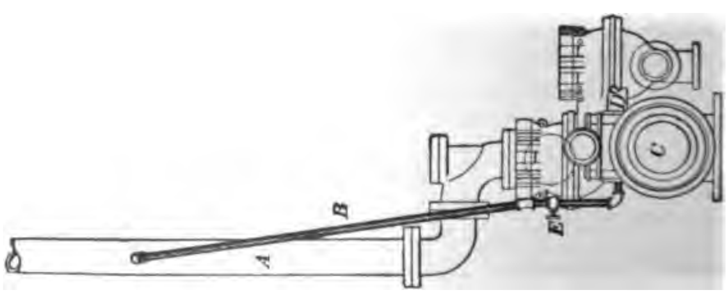


FIG. 721.



zero. Any moisture remaining in the air is instantly converted into ice, the exhaust-passages are stopped, and the engine or pump refuses to work. This is remedied to some extent by surrounding the cylinder walls by a warm-water jacket, the heat being taken from the water and used to raise the temperature of the expanding air. Nor is this condition of affairs helped much by using the full air-pressure throughout the stroke; for the fall in temperature is nearly as great when it exhausts from the cylinder as it is during expansion. In order to use air expansively to any extent, it must be reheated near or in the cylinder before being allowed to do work.

2145. Another device for preventing the freezing of the moisture, and stopping the exhaust-passages through the accumulation of ice, is shown in Fig. 721. *A* is the delivery (column) pipe of a pump operated by compressed air. *B* is a small auxiliary pipe leading from *A* to the exhaust-port of the air-cylinder *C*. This latter pipe enters a short distance into the exhaust-port directly opposite the exhaust-pipe *D*. When the valve *E* is opened, a small stream of water is injected into the exhaust-pipe. The end of the pipe *B*, which is connected with the exhaust-port, has a large number of small holes in it, so that the inflowing water is delivered in the form of a spray, mixing with the exhaust air and raising the temperature to such an extent that the moisture no longer freezes and clogs up the exhaust-passage. This is a cheap and an easily applied device; it works well in actual practice.

2146. Before explaining the methods of reheating the air and the advantages to be derived therefrom, a plant will be described where electricity is used to operate a compressor near the drills. A rough sketch of the plant is shown in Fig. 722. *A* is the motor, which is operated by a dynamo at the surface. The current is conveyed down the shaft and to the motor by means of the wires *E*. The motor drives the air-compressor *B*. *C* is the receiver, which is felted, so as to retain as much of the heat as possible; the

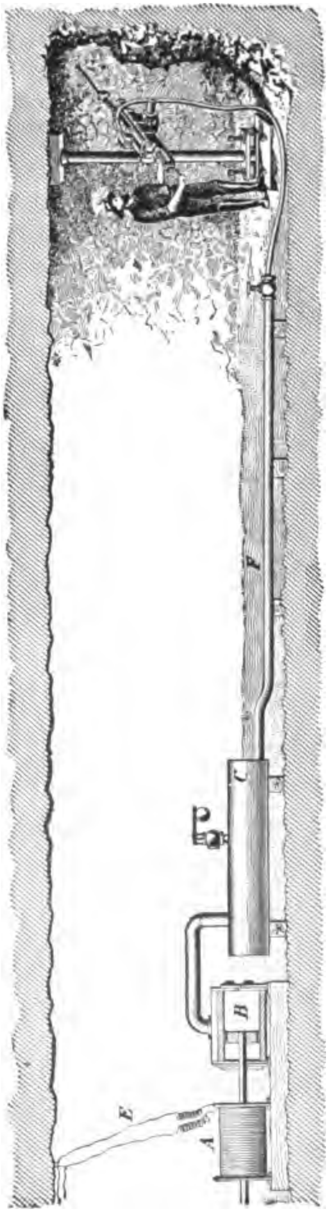


FIG. 722.

pipe F is also felted for the same reason. Since, in this case, the air-compressor is situated close to the drill, but little heat is lost in transmission. Hence, the air is compressed adiabatically, and as much of the heat is retained as is possible, no effort being made to cool the air during compression. The air thus enters the drill very hot, and leaves it at a temperature but a little lower than that of the free air. Since the electric energy can be conveyed for several miles from the generating station with an efficiency of about 80%, and there is practically no loss due to friction of the air, the efficiency of the whole apparatus is quite high.

2147. The advantages to be gained from heating the air after it has cooled, owing to transmission through great distances, are many. The air enters the cylinder at a very high temperature, and can be used expansively without the danger of freezing its moisture and stopping the exhaust-outlet. The work which can be obtained from a given quantity of compressed air is greatly increased, and the cost of reheating is slight. Unless the reheating is

done in the cylinder of the engine itself, which the compressed air drives, and that during expansion (a scheme which has not yet been realized practically), there will be no increase in pressure. This is because air expands when heated, and unless prevented from expanding, the pressure will not increase. The very long column of air behind that which is being reheated acts like an elastic cushion, and the increase of volume is so slight compared with the whole volume in the pipe and receiver that the increase in pressure is not perceptible. The explanation of the increase of work lies in the fact that all work obtained from air, steam, or gas, when used as a motion-producer, is derived from the amount of heat contained in it. When the air is heated, almost the entire amount of heat generated by the combustion is converted directly into work, while in the best steam-engines not more than 12% to 13% of the heat energy of the coal is converted into work.

2148. Fig. 723 shows a reheater in which the air is brought into contact with the fuel. This illustration is taken from a case which was put into actual service in connection with a rock-drill. Immediately above the throttle-valve *A*, and near the steam (air) chest *B* of the rock-drill, was placed an enlarged pipe-fitting *C*, in the interior of which, a little above the center, was fixed a piece of wire gauze *D*; above this gauze, charcoal *F* was thrown, some of it being in an incandescent state. The whole chamber was closed and the compressed air turned on. The air thus brought into direct contact with the burning charcoal was admitted into the drill-cylinder extremely hot.

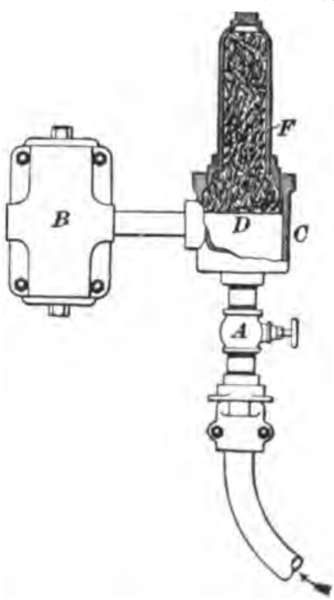


FIG. 723.

Instead of charcoal, a substance called **sestalit** has been used with considerable success, the advantage of sestalit being that it remains ignited for some length of time after the air has been shut off, and the products of combustion are not objectionable when discharged in a confined space.

2149. Fig. 724 shows an electric reheater. *C* is the air-compressor, the compressed air being conveyed through a pipe to the receiver *D*, and thence by means of the

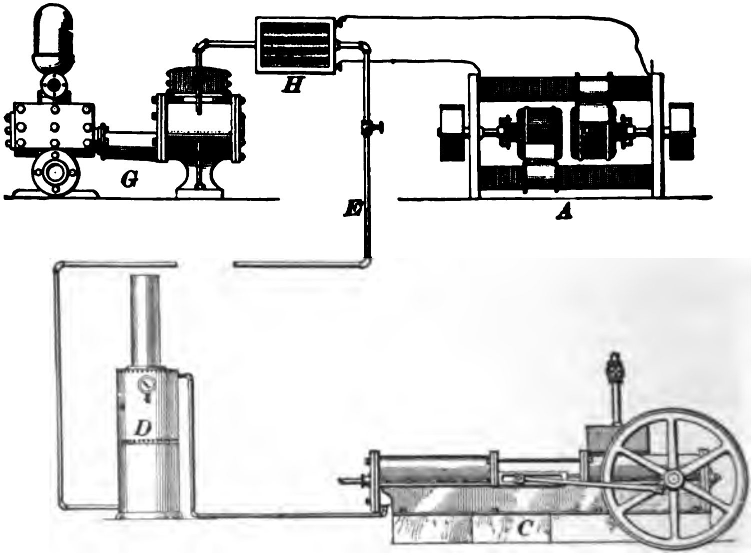


FIG. 724.

pipe *E* to the pump *G*, which is driven by compressed air, and is situated, say, a mile from the compressor. A dynamo *A*, which serves to light the mines, is situated in the engine-room, near the compressor. Near the pump a resistance-coil *H* is placed in a chamber through which the compressed air must pass before entering the pump-cylinder. This resistance-coil is made of some highly refractory substance, which resists the passage of the current to such an extent that the electrical energy is converted into heat, and thus heats the air. This reheater has many advantages. There being no combustion, it is perfectly safe in mines

filled with inflammable gases, and the ease with which it is applied or stopped by simply opening or closing a switch also recommends it. It is a cheap device, and has been recently employed in the shape of a simple coil of wire placed in the air-pipe. Since the loss of electric energy is slight compared with the loss of pressure in the compressed air, the efficiency of the whole system is increased by using the electric wire to reheat the air. It is not, however, as economical as the reheater previously mentioned, but is in many cases more convenient, and for that reason preferable.

Experience has shown that air-engines do not work to advantage at higher temperatures than 350°; hence, the gain through reheating the air is limited. The cost of the fuel consumed during reheating is trifling. With the reheaters commonly used, where the air is heated directly through the combustion of charcoal, it amounts to from one to two cents per horsepower per day. The gain is considerable, and they should be used when practicable.

THE CALCULATION OF THE SIZE OF AN AIR-COMPRESSOR.

2150. It is required to determine the size of the steam and air cylinders of a duplex air-compressor to furnish the compressed air necessary to drive a pump and a set of rock-drills, 28 horsepower being necessary to drive them. To calculate this problem accurately is very tedious and difficult. Moreover, it requires a good knowledge of the application of logarithms and also of higher mathematics to approach the subject with any degree of success. Such being the case, the following approximate method will give results close enough for ordinary practice. The loss of power, in common practice, where compressed air is used to drive machinery in mines and tunnels, is about 70% when common American air-compressors are used and the air is transmitted far enough to lose the heat imparted to it by compression. Where the best compressors are used, the loss is about 60%. In both cases, it is assumed that the air

F. II.—39

has not been reheated before being used. If the best compressors and the best reheating systems are used, the loss may be reduced to about 20%. Assume for the present case that the loss is 60%. Since the horsepower required is 28 and the loss 60%, the horsepower of the engines must be $28 \div .40 = 70$ horsepower. As the engines are to be of the duplex type, each cylinder must develop $70 \div 2 = 35$ horsepower.

2151. To obtain the size of the cylinder, the mean effective pressure (M. E. P.) must be known. This may be obtained in cases like the present, where indicator-cards can not be taken, from formula **144,** using the constants obtained from Table 44, of *Steam-Engines*, Art. **2069.**

2152. Suppose that the boiler pressure in the present case is 70 lb., that the engine cuts off at half stroke, and that it is non-condensing. The constant, taken from Table 44, for ½ cut-off is .847. Using formula **144,** M. E. P. $= .9\,[.847\,(70 + 14.7) - 17] = 49.27$ lb. per sq. in. The diameter of the steam-cylinder may be calculated by the following formula:

$$D = 79.6 \sqrt[3]{\frac{H}{rPN}}, \qquad \textbf{(148.)}$$

in which H = the number of horsepower the engine is to develop;
D = diameter of cylinder in inches;
r = ratio of length of stroke to diameter of cylinder;
P = mean effective pressure per sq. in. on the piston;
N = number of strokes per minute.

In the present case, assume that the stroke is 1¼ times the diameter; then, $r = 1\frac{1}{4}$. Also, that the number of strokes per minute = 300; then, $D = 79.6 \sqrt[3]{\frac{35}{1\frac{1}{4} \times 49.27 \times 300}} = 9.849$ inches, or say 9⅞ in. Length of stroke $= 9\frac{7}{8} \times 1\frac{1}{4} = 12.344$ inches, or say 12⅜ inches. If the air is to be compressed to about 60 or 70 lb., it is good practice to make the air-cylinders the same in size as the steam-cylinders. In the present example, it would be good practice to make all four cylinders 10 by 12 inches.

PHYSICAL PROPERTIES OF AIR AND GASES.

2153. Air is a mechanical mixture of two gases, nitrogen and oxygen, and contains about three parts, by weight, of the former, to one of the latter. As *water* is the most common type of fluids, so *air* is the most common type of gases. It was supposed by the ancients that air had no weight, and it was not until about the year 1650 that it was proven that air really has weight. A cubic inch of air, under ordinary conditions, weighs .31 grain, nearly. The ratio of the weight of air to water is about 1 : 774; that is, air is only $\frac{1}{774}$ as heavy as water. If a vessel made of light material be filled with a gas lighter than air, so that the total weight of the vessel and gas is less than the air they displace, the vessel will rise. It is on this principle that balloons are made.

2154. Since air has weight, it is evident that the enormous quantity of air that constitutes the atmosphere must exert a considerable pressure upon the earth. This is easily proven by taking a long glass tube closed at one end and filling it with mercury. If the finger be placed over the open end so as to keep the mercury from running out, and the tube be inverted and placed in a glass of mercury, as shown in Fig. 725, the mercury in the tube will fall, then rise, and, after a few oscillations, will come to rest at a height above the top of the mercury in the glass equal to about 30 inches. This

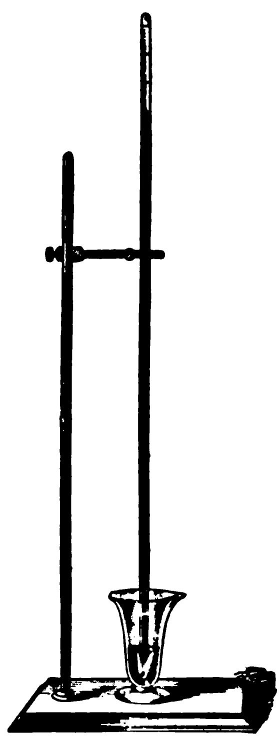


FIG. 725.

height will always be the same under the same atmospheric conditions. Now, if the atmosphere has weight, it must press upon the upper surface of the mercury in the glass with equal intensity upon every square unit, except upon that part of the surface occupied by the tube. In order that there will be equilibrium, the weight of the mercury in the tube must be equal to the pressure of the air upon an area of the upper surface of the mercury in the glass equal to the area of the inside of the tube. Suppose that the area of the inside of the tube is 1 square inch; then, since mercury is 13.6 times as heavy as water, and a cubic inch of water weighs .03617 pound, the weight of the mercurial column is $.03617 \times 13.6 \times 30 = 14.7574$ pounds. The actual height of the mercury is a little less than 30 inches, and the actual weight of a cubic inch of distilled water is a little less than .03617 pound. When these considerations are taken into account, the average weight of the mercurial column at the level of the sea, when the temperature is 60°, is 14.69 pounds, or, practically, 14.7 pounds. Since this weight, exerted upon 1 square inch of the liquid in the glass, just produced equilibrium, it is plain that the pressure of the outside air is 14.7 pounds upon every square inch of surface.

2155. Vacuum.—The space between the upper end of the tube and the upper surface of the mercury is called a *Toricellian vacuum*, or simply a *vacuum*, meaning that it is an entirely empty space, and does not contain any substance, solid, liquid, or gaseous. If there was a gas of some kind there, no matter how small the quantity might be, it would expand, filling the space, and its tension would cause the column of mercury to fall and become shorter, according to the amount of gas or air present. The space is then called a *partial vacuum*. If the mercury fell 1 inch, so that the column was only 29 inches high, we would say, in ordinary language, that there were *29 inches of vacuum*. If it fell 8 inches, we would say that there were 22 inches of vacuum; if it fell 16 inches, we would say that there

were 14 inches of vacuum, etc. Hence, when the vacuum-gauge of a condensing-engine shows 26 inches of vacuum, there is enough air in the condenser to produce a pressure of $\frac{30 - 26}{30} \times 14.7 = \frac{4}{30} \times 14.7 = 1.96$ pounds per square inch.

FIG. 726.

If the tube had been filled with water instead of mercury, the height of the column of water to balance the pressure of the atmosphere would have been $30 \times 13.6 = 408$ inches $= 34$ feet. This means that if a tube be filled with water, inverted, and placed in a dish of water in a manner similar to the experiment made with the mercury, the height of the column of water would be 34 feet.

2156. The **barometer** is an instrument used for measuring the pressure of the atmosphere. There are two kinds in general use, the mercurial barometer and the aneroid barometer. The *mercurial barometer* is shown in Fig. 726. The principle is the same as the inverted tube, shown in Fig. 725. In this case, the tube and cup at the bottom are protected by a brass or iron casing. Near the top of the tube is a graduated scale which can be read to $\frac{1}{1000}$ of an inch by means of a vernier. Attached to the casing is an accurate thermometer for determining the temperature of the outside air at the time the barometric observation is taken. This is necessary, since mercury expands when the temperature is increased, and contracts when the temperature falls; for this reason, a standard temperature is assumed, and all barometer readings are reduced to this temperature. This standard temperature is usually taken at 32° F., at which temperature the height of the mercurial column is 30 inches. Another correction is made for the altitude of the place above sea-level, and a third correction for the effects of capillary attraction.

In Fig. 727 is shown a cut of an *aneroid barometer*. These instruments are made in various sizes, from the size of a watch up to an 8 or 10 inch face. They consist of a cylindrical box of metal, with a top of thin, elastic, corrugated metal. The air is removed from the box. When the atmospheric pressure increases, the top is pressed inwards, and, when it is diminished, the top is pressed outwards by its

FIG. 727.

own elasticity, aided by a spring beneath. These movements of the cover are transmitted and multiplied by a combination of delicate levers, which act upon an index-hand, and cause it to move either to the right or left, over a graduated scale. These barometers are self-correcting (compensated) for variations in temperature. They are very portable, occupying but a small space, and are so delicate that they are said to show a difference in the atmospheric pressure when transferred from the table to the

floor. The mercurial barometer is the standard. With air, as with water, the lower we get, the greater the pressure, and the higher we get, the less the pressure. At the level of the sea, the height of the mercurial column is about 30 inches; at 5,000 feet above the sea, it is 24.7 inches; at 10,000 feet above the sea, it is 20.5 inches; at 15,000 feet, it is 16.9 inches; at 3 miles, it is 16.4 inches, and at 6 miles above the sea-level, it is 8.9 inches.

2157. Density of Air.—The weight of a cubic foot (called the **density**) also varies with the altitude; that is, a cubic foot of air at an elevation of 5,000 feet above the sea-level will not weigh as much as a cubic foot at sea-level. This is proven conclusively by the fact that at a height of 3½ miles the mercurial column measures but 15 inches, indicating that half the weight of the entire atmosphere is below that. It is known that the height of the earth's atmosphere is at least 50 miles; hence, the air just before reaching the limit must be in an exceedingly rarefied state. It is by means of barometers that great heights are measured. The aneroid barometer has the heights marked on the dial, so that they can be read directly. With the mercurial barometer, the heights must be calculated from the reading.

2158. Atmospheric Pressure.—The atmospheric pressure is everywhere present, and presses all objects in all directions with equal force. If a book is laid upon the table, the air presses upon it in every direction with an equal average force of 14.7 pounds per square inch. It would seem as though it would take considerable force to raise a book from the table, since, if the size of the book were 8 inches by 5 inches, the pressure upon it is $8 \times 5 \times 14.7 = 588$ pounds; but there is an equal pressure beneath the book to counteract the pressure on the top. It would now seem as though it would require a great force to open the book, since there are two pressures of 588 pounds each, acting in opposite directions, and tending to crush the book; so it would but for the fact that there is a layer of air between each leaf acting upwards and downwards with a pressure of

14.7 pounds per square inch. If two metal plates be made as perfectly smooth and flat as it is possible to get them, and the edge of one be laid upon the edge of the other, so that one may be slid upon the other, and thus exclude the air, it will take an immense force, compared with the weight of the plates, to separate them. This is because the full pressure of 14.7 pounds per square inch is then exerted upon each plate, with no counteracting equal pressure between them.

If a piece of flat glass be laid upon a flat surface that has been previously moistened with water, it will require considerable force to separate them; this is because the water helps to fill up the pores in the flat surface and glass, and thus creates a partial vacuum between the glass and the surface, thereby reducing the counter-pressure beneath the glass.

2159. Tension of Gases.—In Fig. 725, the space above the column of mercury was said to be a vacuum, and that if any gas or air was present it would expand, its tension forcing the column of mercury downwards. If enough gas is admitted to cause the mercury to stand at 15 inches, the tension of the gas is evidently $\frac{14.7}{2} = 7.35$ pounds per square inch, since the pressure of the outside air of 14.7 pounds per square inch balances only 15 inches, instead of 30 inches of mercury; that is, it balances only half as much as it would if there were no gas in the tube; therefore, the tension (pressure) of the gas in the tube is 7.35 pounds. If more gas is admitted, until the top of the mercurial column is just level with the mercury in the cup, the gas in the tube has then a tension equal to the outside pressure of the atmosphere. Suppose that the bottom of the tube is fitted with a piston, and that the total length of the inside of the tube is 36 inches. If the piston be shoved upwards so that the space occupied by the gas is 18 inches long, instead of 36 inches, the temperature remaining the same as before, it will be found that the tension of the gas within the tube is 29.4 pounds. It will be noticed that the volume occupied by the gas is only half that in the tube before the

piston was moved, while the pressure is twice as great, since $14.7 \times 2 = 29.4$ pounds. If the piston be shoved up so that the space occupied by the gas is only 9 inches instead of 18 inches, the temperature still remaining the same, the pressure will be found to be 58.8 pounds per square inch. The volume has again been reduced one-half, and the pressure increased two times, since $29.4 \times 2 = 58.8$ pounds. The volume now occupied by the gas is 9 inches long, whereas, before the piston was moved, it was 36 inches long; as the tube was assumed to be of uniform diameter throughout its length, the volume is now $\frac{9}{36} = \frac{1}{4}$ of its original volume, and its pressure is $\frac{58.8}{14.7} = 4$ times its original pressure. Moreover, if the temperature of the confined gas remains the same, the pressure and volume will always vary in a similar way. The law which states these effects is called *Mariotte's law.*

2160. Mariotte's Law.—*The temperature remaining the same, the volume of a given quantity of gas varies inversely as the pressure.*

The meaning of this is: If the volume of the gas is diminished to $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{5}$, etc., of its former volume, the tension will be increased 2, 3, 5, etc., times, or, if the outside pressure be increased 2, 3, 5, etc., times, the volume of the gas will be diminished to $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{5}$, etc., of its original volume, the temperature remaining constant. It also means that if a gas is under a certain pressure, and the pressure is diminished to $\frac{1}{2}$, $\frac{1}{4}$, $\frac{1}{10}$, etc., of its original pressure, that the volume of the confined gas will be increased 2, 4, 10, etc., times, its tension decreasing at the same rate.

Suppose 3 cubic feet of air to be under a pressure of 60 pounds per square inch in a cylinder fitted with a movable piston; then, the product of the volume and pressure is $3 \times 60 = 180$. Let the volume be increased to 6 cubic feet; then, the pressure will be 30 pounds per square inch, and $30 \times 6 = 180$ as before. Let the volume be increased to 24 cubic feet; it is then $\frac{24}{3} = 8$ times its original volume, and the

pressure is $\frac{1}{8}$ of its original pressure, or $60 \times \frac{1}{8} = 7\frac{1}{2}$ pounds, and $24 \times 7\frac{1}{2} = 180$, as in the two preceding cases. It will now be noticed that if a gas be enclosed within a confined space, and allowed to expand without losing any heat, *the product of the pressure and the corresponding volume for one position of the piston is the same as for any other position of the piston.* If the piston was to compress the air, the rule would still hold good.

Let p = pressure for one position of the piston;
p_1 = pressure for any other position of the piston;
v = volume corresponding to the pressure p;
v_1 = volume corresponding to the pressure p_1.

Then, $$pv = p_1 v_1; \qquad \textbf{(149.)}$$

also, $$p_1 = \frac{pv}{v_1}; \qquad \textbf{(150.)}$$

and $$v_1 = \frac{pv}{p_1}. \qquad \textbf{(151.)}$$

Knowing the volume and the pressure for any position of the piston and the volume for any other position, the pressure may be calculated by formula **150,** or if the pressure is known for any other position, the volume may be calculated by formula **151.**

EXAMPLE.—If 1.875 cubic feet of air be under a pressure of 72 pounds per square inch, (*a*) what will be the pressure when the volume is increased to 2 cubic feet? (*b*) to 3 cubic feet? (*c*) to 9 cubic feet?

SOLUTION.—(*a*) $p_1 = \frac{pv}{v_1} = \frac{72 \times 1.875}{2} = 67\frac{1}{2}$ pounds per square inch. Ans.

(*b*) $p_1 = \frac{72 \times 1.875}{3} = 45$ pounds per square inch. Ans.

(*c*) $p_1 = \frac{72 \times 1.875}{9} = 15$ pounds per square inch. Ans.

EXAMPLE.—If 10 cubic feet of air have a tension of 5.6 pounds per square inch, (*a*) what is the volume when the tension is 4 pounds? (*b*) 8 pounds? (*c*) 25 pounds? (*d*) 100 pounds?

SOLUTION.—(*a*) $v_1 = \frac{p\,v}{p_1} = \frac{5.6 \times 10}{4} = 14$ cubic feet. Ans.

(*b*) $v_1 = \frac{5.6 \times 10}{8} = 7$ cubic feet. Ans.

(*c*) $v_1 = \frac{5.6 \times 10}{25} = 2.24$ cubic feet. Ans.

(*d*) $v_1 = \frac{5.6 \times 10}{100} = .56$ cubic foot. Ans.

2161. As a necessary consequence of Mariotte's law, it may be stated that *the density of a gas varies directly as the pressure and inversely as the volume;* that is, *the density increases as the pressure increases, and decreases as the volume increases.*

This is evident, since if a gas has a tension of two atmospheres, or $14.7 \times 2 = 29.4$ pounds per square inch, it will weigh twice as much as the same volume would if the tension was one atmosphere, or 14.7 pounds per square inch. For, let the volume be increased until it is twice as great as the original volume, the tension will then be one atmosphere. The total weight of the gas has not been changed, but there are now 2 cubic feet for every 1 cubic foot of the original volume, and the weight of 1 cubic foot now is only half as great as before. Thus, the density decreases as the volume increases, and as an increase of pressure causes a decrease of volume, the density increases as the pressure increases.

Let D be the density corresponding to the pressure p and volume v, and D_1 be the density corresponding to the pressure p_1 and volume v_1. Then,

$$p : D :: p_1 : D_1, \text{ or } p\,D_1 = p_1\,D, \qquad \textbf{(152.)}$$

and $$v : D_1 :: v_1 : D, \text{ or } v\,D = v_1\,D_1. \qquad \textbf{(153.)}$$

2162. Since the weight is proportional to the density, the weights may be used in place of the densities in formulas **152** and **153**. Thus, let W be the weight of a quantity of air or other gas whose volume is v and pressure is p; let W_1 be the weight of the same quantity when the volume is v_1 and pressure is p_1. Then,

$$p : W :: p_1 : W_1, \text{ or } p\,W_1 = p_1\,W; \qquad \textbf{(154.)}$$

$$v : W_1 :: v_1 : W, \text{ or } v\,W = v_1\,W_1. \qquad \textbf{(155.)}$$

EXAMPLE.—The weight of 1 cubic foot of air at a temperature of 60° F. and under a pressure of 1 atmosphere (14.7 pounds per square inch) is .0763 pound; what would be the weight per cubic foot if the volume was compressed until the tension was 5 atmospheres, the temperature still being 60°?

SOLUTION.—Using formula **154**,

$p : W :: p_1 : W_1$, or $1 : .0763 :: 5 : W_1$, or $W_1 = .3815$ lb. Ans.

EXAMPLE.—If in the last example the air had expanded until the tension was 5 pounds per square inch, what would have been its weight per cubic foot?

SOLUTION.—Here $p = 14.7$, $p_1 = 5$, and $W = .0763$. Hence, using the same formula, $14.7 : .0763 :: 5 : W_1$, or $W_1 = .02595$ lb. Ans.

EXAMPLE.—If 6.75 cubic feet of air at a temperature of 60° F., and a pressure of one atmosphere, are compressed to 2.25 cubic feet (the temperature still remaining 60° F.), what is the weight of a cubic foot of the compressed air?

SOLUTION.—Using formula **155**,

$$v : W_1 :: v_1 : W, \text{ or } 6.75 : W_1 :: 2.25 : .0763$$

or

$$W_1 = \frac{.0763 \times 6.75}{2.25} = .2289 \text{ lb. Ans.}$$

2163. Relation of Temperature to Volume.—In all that has been said before, it has been stated that the temperature was constant; the reason for this will now be explained. Suppose 5 cubic feet of air to be confined in a cylinder whose area is 10 square inches, placed in a vacuum so that there will be no pressure due to the atmosphere, and the cylinder be fitted with a piston weighing say 100 pounds. The tension of the gas will be $\frac{100}{10} = 10$ pounds per square inch. Suppose that the temperature of the air is 32° F., and that it is heated until the temperature is 33° F., or the temperature is increased 1°; it will be found that the piston has risen a certain amount, and, consequently, the volume has increased, while the pressure is the same as before, or 10 pounds per square inch. If more heat is applied until the temperature of the gas is 34° F., it will be found that the piston has again risen and the volume again increased, while the pressure still remains the same. It will be found that for every increase of temperature there will be a corresponding increase of volume. The law which expresses this change is called *Gay-Lussac's law*.

2164. Gay-Lussac's Law.—*If the pressure remains constant, every increase of temperature of 1° F. produces in a given quantity of gas an expansion of $\frac{1}{491}$ of its volume at 32° F.*

If the pressure remains constant, it will also be found that every decrease of temperature of 1° F. will cause a decrease of $\frac{1}{491}$ of the volume at 32° F.

Let v = volume of gas before heating;
v_1 = volume of gas after heating;
t = temperature corresponding to volume v;
t_1 = temperature corresponding to volume v_1.

Then, $$v_1 = v\left(\frac{459 + t_1}{459 + t}\right). \qquad \textbf{(156.)}$$

That is, *the volume of gas after heating (or cooling) equals the original volume multiplied by 459 plus the final temperature, divided by 459 plus the original temperature.*

EXAMPLE.—When 5 cubic feet of air at a temperature of 45° are heated under constant pressure up to 177°, what is its new volume?

SOLUTION.— $v_1 = v\left(\frac{459 + t_1}{459 + t}\right) = 5 \times \left(\frac{636}{504}\right) = 6.309$ cu. ft. Ans.

Suppose that a certain volume of gas is confined in a vessel so that it can not expand; in other words, suppose that the piston of the cylinder before mentioned to be fastened so that it can not move. Let a gauge be placed on the cylinder so that the tension of the confined gas can be registered. If the gas is heated, it will be found that for every increase of temperature of 1° F. there will be a corresponding increase of $\frac{1}{491}$ of the tension at 32° F.; that is, the volume remaining constant, the tension increases $\frac{1}{491}$ of the tension at 32° F. for every degree rise of temperature.

Let p = the original tension;
t = the corresponding temperature;
t_1 = any higher temperature;
p_1 = corresponding tension.

Then, $$p_1 = p\left(\frac{459 + t_1}{459 + t}\right). \qquad \textbf{(157.)}$$

That is, *if a certain quantity of gas is heated from $t°$ to $t_1°$, the volume remaining constant, the resulting tension p_1 will be equal to the original tension multiplied by 459 plus the final temperature, divided by 459 plus the original temperature.*

EXAMPLE.—If a certain quantity of air is heated under constant volume from 45° to 177°, what is the resulting tension, the original tension being 14.7 pounds per square inch ?

SOLUTION.— $p_1 = p\left(\frac{459 + t_1}{459 + t}\right) = 14.7 \times \left(\frac{636}{504}\right) = 18.55$ lb. per sq. in. Ans.

2165. Absolute Zero.—According to the modern and now generally accepted theory of heat, the atoms and molecules of all bodies are in an incessant state of vibration. The vibratory movement in the liquids is faster than in the solids; it is faster in the gases than in either of the others. Any increase of heat increases the vibrations, and a decrease of heat decreases them. From experiments and calculations based upon higher mathematics, it has been concluded that at 459° below zero on the Fahrenheit scale, or at 273° below zero on the Centigrade scale, all these vibrations cease. This point is called the *absolute zero*, and all temperatures reckoned from this point are called the *absolute temperatures.* The point of absolute zero has never been reached nor closely approached, the lowest recorded temperature being 360° F. below zero, but, nevertheless, it has a meaning, and is used in many formulas, being nearly always denoted by T. The ordinary temperatures are denoted by t. When the word temperature alone is used, the meaning is the same as ordinarily used, but when absolute temperature is specified, 459° F. must be added to the temperature. The absolute temperature corresponding to 212° F. is $459° + 212° = 671°$ F. If the absolute temperature is given, the ordinary temperature may be found by subtracting 459° from the absolute temperature. Thus, the absolute temperature being 520° F., what is the temperature ?

$$520° - 459° = 61° \text{ F.}$$

Let P = pressure of air per square inch;
V = volume of air in cubic feet;
T = absolute temperature of air;
W = weight of air in pounds.

Then, $$P = \frac{.37052\,W\,T}{V}; \qquad (158.)$$

$$V = \frac{.37052\,W\,T}{P}; \qquad (159.)$$

$$T = \frac{P\,V}{.37052\,W}; \qquad (160.)$$

$$W = \frac{P\,V}{.37052\,T}. \qquad (161.)$$

EXAMPLE.—If 40 cubic feet of air weigh 3.5 pounds, and have a temperature of 82°, what is the pressure (tension) in pounds per square inch?

SOLUTION.— $P = \frac{.37052\,W\,T}{V} = \frac{.37052 \times 3.5 \times 541}{40} = 17.539$ lb. per sq. in. Ans.

EXAMPLE.—What is the volume in cubic feet of a certain quantity of air having a tension of 17.539 pounds per square inch, a temperature of 80°, and which weighs 3.5 pounds?

SOLUTION.— $V = \frac{.37052\,W\,T}{P} = \frac{.37052 \times 3.5 \times 541}{17.539} = 40$ cu. ft. Ans.

EXAMPLE.—If 40 cubic feet of air having a tension of 17.539 pounds per square inch weigh 3.5 pounds, what is the temperature?

SOLUTION.— $T = \frac{P\,V}{.37052\,W} = \frac{17.539 \times 40}{.37052 \times 3.5} = 541°$, nearly. Hence, $541° - 459° = 82°$. Ans.

EXAMPLE.—If 40 cubic feet of air have a tension of 17.539 pounds per square inch, and a temperature of 82°, (a) what is its weight? (b) what is its weight per cubic foot?

SOLUTION.—(a) $W = \frac{P\,V}{.37052\,T} = \frac{17.539 \times 40}{.37052 \times 541} = 3.5$ lb. Ans.

(b) $3.5 \div 40 = .0875$ lb. per cu. ft. Ans.

2166. Mixing of Gases.—If two gases which do not act chemically upon each other are mixed together and allowed to stand, it will be found that after a time the two

liquids have separated, and the heavier has fallen to the bottom. If two equal vessels containing gases of different densities be put in communication with each other, they will be found to have mixed in equal proportions after a short time. If one vessel be above the other, and the heavier gas be in the lower vessel, the same result will occur. The greater the difference of the densities of the two gases, the quicker they will mix. It is assumed that no chemical action takes place between the two gases. When the two gases have the same temperature and pressure, the pressure of the mixture will be the same; this is evident, since the total volume has not been changed, and unless the volume or temperature changes, the pressure can not change. This property of the mixing of gases is a very valuable one, since, if they acted like liquids, carbonic acid gas (the result of combustion), which is $1\frac{1}{2}$ times as heavy as air, would remain next to the earth, instead of dispersing into the atmosphere, the result being that no animal life could exist.

2167. Mixtures of Equal Volumes of Gases Having Unequal Pressures.—*If two gases having the same volume and temperature, but different pressures, be mixed in a vessel whose volume equals one of the equal volumes of the gas, the pressure of the mixture will be equal to the sum of the two pressures, provided that the temperature remains the same as before.*

EXAMPLE.—Two vessels containing 3 cubic feet of gas, each at a temperature of 60°, and at a pressure of 40 pounds and 25 pounds per square inch, respectively, are placed in communication with each other, and all the gas is compressed into one vessel. If the temperature of the mixture is also 60°, what is the pressure?

SOLUTION.—According to the rule just given, the pressure will be $40 + 25 = 65$ lb. per sq. in. Ans.

2168. Mixture of Two Gases Having Unequal Volumes and Pressures.—

Let v and p be the volume and pressure of one of the gases.
Let v_1 and p_1 be the volume and pressure of the other gas.
Let V and P be the volume and pressure of the mixture.

Then, if the temperature remains the same,

$$P = \frac{p\,v + p_1\,v_1}{V}; \qquad (162.)$$

$$V = \frac{p\,v + p_1\,v_1}{P}. \qquad (163.)$$

EXAMPLE.—Two gases of the same temperature, having volumes of 7 cubic feet and 4½ cubic feet, and tensions of 25 pounds and 18 pounds per square inch, respectively, are mixed together in a vessel whose volume is 10 cubic feet. The temperature remaining the same, what is the resulting pressure?

SOLUTION.— $P = \frac{p\,v + p_1\,v_1}{V} = \frac{(25 \times 7) + (18 \times 4\frac{1}{2})}{10} = \frac{256}{10} = 25.6$ lb. per sq. in. Ans.

EXAMPLE.—What must be the volume of a vessel which will hold two gases whose volumes are 7 cubic feet and 4½ cubic feet, and whose tensions are 25 pounds and 18 pounds per square inch, respectively, in order that the pressure may be 25.6 pounds per square inch, the temperature remaining the same throughout?

SOLUTION.— $V = \frac{p\,v + p_1\,v_1}{P} = \frac{(25 \times 7) + (18 \times 4\frac{1}{2})}{25.6} = 10$ cu. ft. Ans.

HYDROMECHANICS AND PUMPING.

HYDROSTATICS.

LAWS OF LIQUID PRESSURE.

2169. Hydrostatics treats of liquids at rest under the action of forces. Liquids are very nearly *incompressible.* A pressure of 15 pounds per square inch compresses water less than $\frac{1}{100000}$ of its volume.

2170. Fig. 728 represents two cylindrical vessels of exactly the same size. The vessel *a* is fitted with a wooden block of the same size as the cylinder, and can move in it; the vessel *b* is filled with water, whose depth is the same as the length of the wooden block in *a*. Both vessels are fitted with air-tight pistons *P*, whose areas are each 10 sq. in.

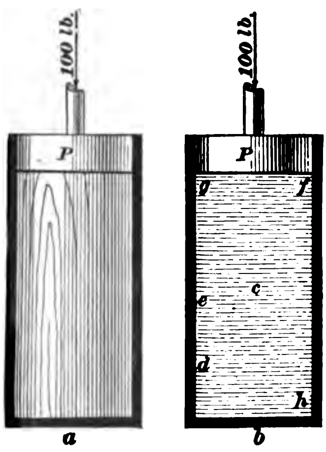


FIG. 728.

Suppose, for convenience, that the weights of the cylinders, pistons, block, and water be neglected, and that a force of 100 pounds be applied to both pistons. The pressure per square inch will be $\frac{100}{10} = 10$ pounds. In the vessel *a*, this pressure will be transmitted to the bottom of the vessel, and will be 10 pounds per square inch; it is easy to see that there will be no pressure on the sides. In the vessel *b*, an entirely different result is obtained. The pressure on the bottom will be the same as in the other case,

that is, 10 pounds per square inch, but, owing to the fact that the molecules of the water are perfectly free to move, this pressure of 10 pounds per square inch is *transmitted in every direction with the same intensity;* that is to say, the pressure at any point, *c*, *d*, *e*, *f*, *g*, *h*, etc., due to the force of 100 pounds, is exactly the same, and equals 10 pounds per square inch.

This may be easily proven experimentally by means of an apparatus like that shown in Fig. 729. Let the area of the pistons *a*, *b*, *c*, *d*, *e*, and *f* be 20, 7, 1, 6, 8, and 4 sq. in., respectively.

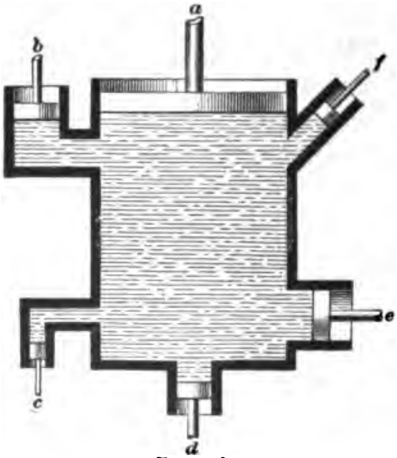


FIG. 729.

If the pressure due to the weight of the water be neglected, and a force of 5 pounds be applied at *c* (whose area is 1 sq. in.), a pressure of 5 pounds per square inch will be transmitted in all directions; in order that there shall be no movement, a force of $6 \times 5 = 30$ pounds must be applied at *d*, 40 pounds at *e*, 20 pounds at *f*, 100 pounds at *a*, and 35 pounds at *b*.

If a force of 99 pounds were applied to *a*, instead of 100 pounds, the piston *a* would rise, and the other pistons *b*, *c*, *d*, *e*, and *f* would move inwards; but, if the force applied to *a* were 100 pounds, they would all be in equilibrium. Suppose 101 pounds to be applied at *a*; the pressure per square inch would be $\frac{101}{20} = 5.05$ pounds, which would be transmitted in all directions; and, since the pressure due to *c* is only 5 pounds per square inch, it is now evident that the piston *a* will move downwards, and the pistons *b*, *c*, *d*, *e*, and *f* will be forced outwards.

2171. The whole may be summed up as follows:

The pressure per unit of area exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and

acts with the same intensity upon all surfaces in a direction at right angles to those surfaces.

This law was first discovered by Pascal, and is the most important in hydromechanics. Its meaning should be thoroughly understood.

EXAMPLE.—If the area of the piston *e* in Fig. 729 is 8.25 sq. in., and a force of 150 pounds is applied to it, what forces must be applied to the other pistons to keep the water in equilibrium, assuming that their areas were the same as given before ?

SOLUTION.— $\frac{150}{8.25} = 18.182$ pounds per square inch, nearly.

$$\left.\begin{array}{l} 20 \times 18.182 = 363.64 \text{ lb.} = \text{force to balance } a. \\ 7 \times 18.182 = 127.274 \text{ lb.} = \text{force to balance } b. \\ 1 \times 18.182 = 18.182 \text{ lb.} = \text{force to balance } c. \\ 6 \times 18.182 = 109.092 \text{ lb.} = \text{force to balance } d. \\ 4 \times 18.182 = 72.728 \text{ lb.} = \text{force to balance } f. \end{array}\right\} \text{Ans.}$$

The pressure due to the weight of a liquid may be downwards, upwards, or sideways.

2172. Downward Pressure.—In Fig. 730 the pressure on the bottom of the vessel *a* is, of course, equal to the weight of the water it contains. If the area of the bottom of the vessel *b* and the depth of the liquid contained in it are the same as in the vessel *a*, the pressure on the bottom of *b* will be the same as on the bottom of *a*. Suppose the bottoms of the vessels *a* and *b* are 6 inches square, that the part *c d*, in the vessel *b*, is 2 inches square, and that the vessels are filled with water. The weight of 1 cubic inch of water is $\frac{62.5}{1,728} = .03617$ pound. The number of cubic inches in $a = 6 \times 6 \times 24 = 864$ cubic inches. The weight of the water is $864 \times .03617 = 31.25$ pounds. Hence, the total pressure on the bottom of the vessel *a* is 31.25 pounds, or

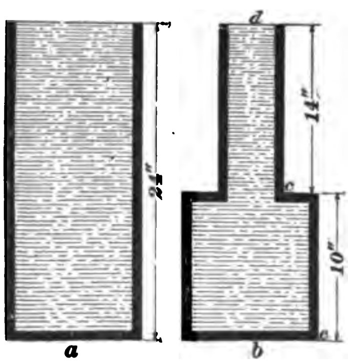


FIG. 730.

0.868 pound per square inch. The pressure in *b*, due to the weight contained in the part *b c*, is $6 \times 6 \times 10 \times .03617 = 13.02$ pounds. The weight of the part contained in *c d* is $2 \times 2 \times 14 \times .03617 = 2.0255$ pounds, and the weight per square inch of area in *c d* is $\frac{2.0255}{4} = .5064$ pound.

According to Pascal's law, this weight (pressure) is transmitted equally in all directions; therefore, every square inch of the top of the large part of the vessel *b* will be subjected to a pressure of .5064 pound. The area of the part *b c* is $6 \times 6 = 36$ sq. in., and the total pressure due to the weight of the water in the small part will be $.5064 \times 36 = 18.23$ pounds. Hence, the total pressure on the bottom of *b* will be $13.02 + 18.23 = 31.25$ pounds, the same result as in the case of the vessel *a*.

If an additional pressure of 10 pounds per square inch were applied to the upper surface of both vessels, the total pressure on their bottoms would be $31.25 + (6 \times 6 \times 10) = 31.25 + 360 = 391.25$ pounds.

If in this case this pressure were obtained by means of a weight placed on a piston, as shown in Figs. 728 and 729, the weight for the vessel *a* would be $6 \times 6 \times 10 = 360$ pounds, and for the vessel *b*, $2 \times 2 \times 10 = 40$ pounds.

2173. The general law for the downward pressure upon the bottom of any vessel:

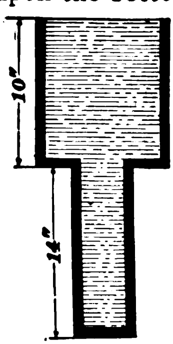


FIG. 731.

The pressure upon the bottom of a vessel containing a fluid is independent of the shape of the vessel, and is equal to the weight of a prism of the fluid whose base is the same as the bottom of the vessel, and whose altitude is the distance between the bottom and the upper surface of the fluid, plus the pressure per unit of area upon the upper surface of the fluid, multiplied by the area of the bottom of the vessel.

Suppose that the vessel *b*, Fig. 730, were inverted, as shown in Fig. 731; the pressure upon the bottom

will still be 0.868 pound per square inch, but it will require a weight of 3,490 pounds to be placed upon a piston at the upper surface to make the pressure on the bottom 391.25 pounds, instead of a weight of 40 pounds, as in the other case.

EXAMPLE.—A vessel filled with salt water, having a specific gravity of 1.03, has a circular bottom 13 inches in diameter. The top of the vessel is fitted with a piston 3 inches in diameter, on which is laid a weight of 75 pounds. What is the total pressure on the bottom, if the depth of the water is 18 inches?

SOLUTION.—The weight of 1 cubic inch of the water is $\frac{62.5 \times 1.03}{1,728} =$ .037254 lb. $13 \times 13 \times .7854 \times 18 \times .037254 = 89.01$ pounds = the pressure due to the weight of the water. $\frac{75}{3 \times 3 \times .7854} = 10.61$ pounds per square inch due to the weight on the piston. $13 \times 13 \times .7854 \times 10.61 =$ 1,408.29 pounds.

Total pressure $= 1,408.29 + 89.01 = 1,497.3$ pounds. Ans.

2174. Upward Pressure.—In Fig. 732 is represented a vessel of exactly the same size as that represented in Fig. 731. There is no upward pressure on the surface *c* due to the weight of the water in the large part *c d*, but there is an upward pressure on *c* due to the weight of the water in the small part *b c*. The pressure per square inch due to the weight of the water in *b c* was found to be .5064 pound (see Art. **2172**); the area of the upper surface *c* of the large part *c d* is evidently $(6 \times 6) - (2 \times 2) = 36 - 4 = 32$ sq. in., and the total upward pressure due to the weight of the water is $.5064 \times 32 = 16.2$ pounds.

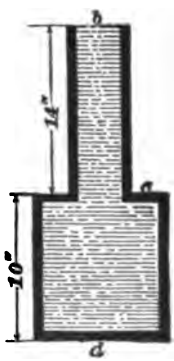


FIG. 732.

If an additional pressure of 10 pounds per square inch were applied to a piston fitting the top of the vessel, the total upward pressure on the surface *c* would be

$$16.2 + (32 \times 10) = 336.2 \text{ pounds.}$$

2175. General law for upward pressure:

The upward pressure on any submerged horizontal surface equals the weight of a prism of the liquid, whose base has an area equal to the area of the submerged surface, and whose

altitude is the distance between the submerged surface and the upper surface of the liquid, plus the pressure per unit of area on the upper surface of the fluid, multiplied by the area of the submerged surface.

EXAMPLE.—A horizontal surface, 6 inches by 4 inches, is submerged in a vessel of water 26 inches below the upper surface. If the pressure on the water is 16 pounds per square inch, what is the total upward pressure on the horizontal surface?

SOLUTION.— $4 \times 6 \times 26 \times .03617 = 22.57$ pounds, the upward pressure due to the weight of the water.

$6 \times 4 \times 16 = 384$ pounds, the upward pressure due to the outside pressure of 16 pounds per square inch.

The total upward pressure $= 384 + 22.57 = 406.57$ pounds. Ans.

2176. Lateral (Sideways) Pressure.—Suppose the top of the vessel shown in Fig. 733 is 10 inches square, and that the projections at *a* and *b* are 1 inch × 1 inch, and 10 inches long.

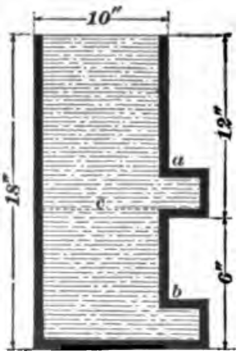


FIG. 733.

The pressure per square inch on the bottom of the vessel, due to the weight of the liquid, is $1 \times 1 \times 18 \times$ the weight of a cubic inch of the liquid.

The pressure at a depth equal to the distance of the upper surface *b* is $1 \times 1 \times 17 \times$ the weight of a cubic inch of the liquid.

Since both of these pressures are transmitted in every direction, they are also transmitted laterally (sideways), and the *pressure per unit of area on the projection b is a mean between the two*, and equals $1 \times 1 \times 17\frac{1}{2} \times$ the weight of a cubic inch of the liquid.

To find the lateral pressure on the projection *a*, imagine that the dotted line *c* is the bottom of the vessel; then the conditions would be the same as in the preceding case, except that the depth is not so great.

The lateral pressure on *a* is thus seen to be $1 \times 1 \times 11\frac{1}{2} \times$ the weight of a cubic inch of the liquid.

2177. General law for lateral pressure:

The pressure upon any vertical surface, due to the weight of

the liquid, is equal to the weight of a prism of the liquid whose base has the same area as the vertical surface, and whose altitude is the depth of the center of gravity of the vertical surface below the level of the liquid.

Any additional pressure is to be added, as in the previous cases.

EXAMPLE.—A well 3 feet in diameter and 20 feet deep is filled with water; what is the pressure on a strip of the wall 1 inch wide, the center of which is 1 foot from the bottom? What is the pressure on the bottom? What is the upward pressure per square inch, 2 feet 6 inches from the bottom?

SOLUTION.— $1 \times 36 \times 3.1416 = 113.1$ sq. in., the area of the strip. $113.1 \times 19 \times 12 \times .03617 = 932.71$ pounds, total pressure upon the strip. Ans.

The pressure per square inch would be $\frac{932.71}{113.1} = 8.247$ pounds, nearly.

$36 \times 36 \times .7854 \times 20 \times 12 \times .03617 = 8{,}836$ pounds, the pressure on the bottom. Ans.

$20 - 2.5 = 17.5$. $1 \times 17.5 \times 12 \times .03617 = 7.596$ pounds, the upward pressure per square inch, 2 feet 6 inches from the bottom. Ans.

2178. The effects of lateral pressure are illustrated in Fig. 734; *e* is a tall vessel having a stop-cock near its base, and arranged to float upon the water, as shown. When this

FIG. 734.

vessel is filled with water, the lateral pressures at any two points of the surface of the vessel and opposite to each other are equal. Being equal, and acting in opposite directions,

they destroy each other, and no motion can result; but if the stop-cock be opened, there will be no resistance to that pressure acting on the surface equal to the area of the opening, and it will cause the water to flow out, while its equal and opposite force will cause the vessel to move backwards through the water in a direction opposite to that of the spouting water.

2179. The laws of liquid pressure given in the preceding articles may be embraced in the following formula:

$$P = a\,(d\,w + p), \qquad \textbf{(164.)}$$

where a = area of a submerged surface in square inches;
d = distance in inches of center of gravity of surface from surface of liquid;
w = weight of a cubic inch of the fluid in pounds;
p = pressure on surface of liquid in pounds per square inch;
P = total pressure on submerged surface in pounds.

2180. Since the pressure on the bottom of a vessel due to the weight of the liquid is dependent only upon the height of the liquid, and not upon the shape of the vessel, it follows that if a vessel has a number of radiating tubes, as shown in Fig. 735, the water in each tube will be on the same level, no matter what may be the shape of the tubes. For, if the water were higher in one tube than in the others, the downward pressure on the bottom due to the height of the water in this tube would be greater than that due to the height of the water in the other tubes. Consequently, the upward pressure would also be greater, the equilibrium would be destroyed, and the water would flow from this tube into the

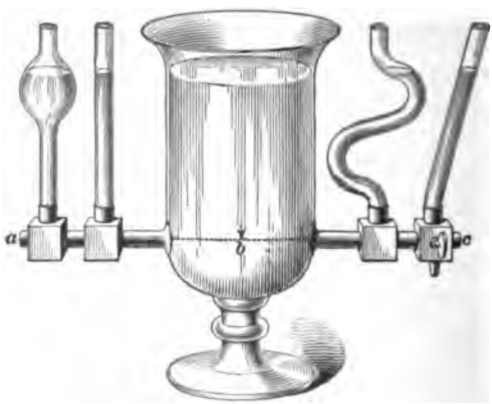


FIG. 735.

vessel, and rise in the other tubes until it was at the same level in all, when it would be in equilibrium. This principle is expressed in the familiar saying, *water seeks its level.*

This explains why city water-reservoirs are located on high elevations, and why water on leaving the hose-nozzle spouts so high.

If there were no resistance by friction and air, the water would spout to a height equal to the level of the water in the reservoirs. If a long pipe whose length was equal to the vertical distance between the nozzle and the level of the water in the reservoir were attached to the nozzle, the water would just reach the end of the pipe. If the pipe were lowered slightly, the water would trickle out. Fountains, canal-locks, and artesian wells are examples of the application of this principle.

EXAMPLE.—The water-level in a city reservoir is 150 feet above the level of the street; what is the pressure of the water per square inch on the hydrant?

SOLUTION.— $1 \times 150 \times 12 \times .03617 = 65.106$ pounds per square inch. Ans.

2181. In Fig. 736, let the area of the piston *a* be 1 square inch, of *b* 40 square inches. According to Pascal's law, 1 pound placed upon *a* will balance 40 pounds placed upon *b*.

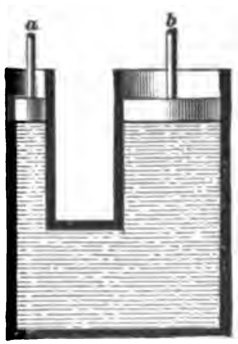


FIG. 736.

Suppose that *a* moves downwards 10 inches, then 10 cubic inches of water will be forced into the tube *b*. This will be distributed over the entire area of the tube *b*, in the form of a cylinder, whose cubical contents must be 10 cubic inches, whose base has an area of 40 square inches, and whose altitude must be $\frac{10}{40} = \frac{1}{4}$ of an inch; that is, a movement of 10 inches of the piston *a* will cause a movement of $\frac{1}{4}$ of an inch in the piston *b*.

This is analogous to the old principle of machines: *The power, multiplied by the distance through which it moves*

equals the weight multiplied by the distance through which it moves.

2182. The foregoing principles are made use of in the hydraulic press represented in Fig. 737. As the lever O is

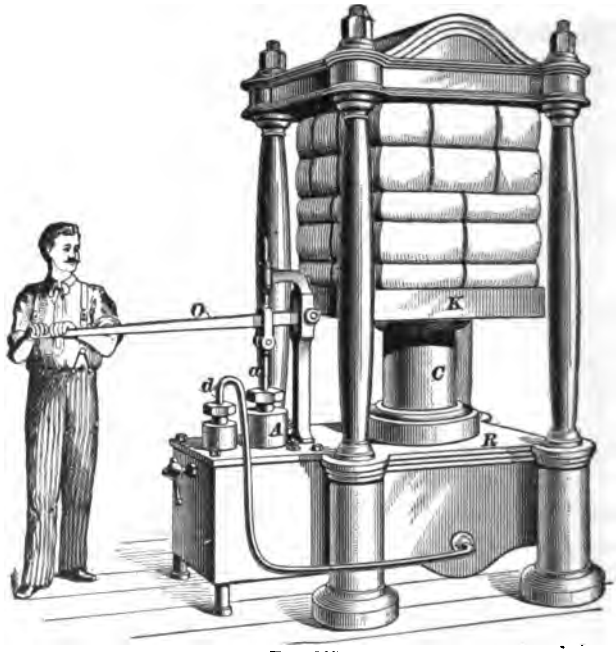


Fig. 737.

depressed, the piston a is forced down upon the water in the cylinder A. The water is forced through the bent tube d into the cylinder in which the large piston C works, and causes C to rise, thus lifting the platform K, and compressing the bales. If the area of a be $\frac{1}{2}$ sq. in., and that of C be 50 sq. in., it is evident, from the explanation of Fig. 736, that a force of 10 pounds on the piston a will lift a load of $\frac{10}{.5} \times 50 = 1{,}000$ pounds on the piston C. If, now, the length of the lever between the hand and the fulcrum is 10 times the length between the fulcrum and the piston a, a force of 10 pounds on the end of the lever will exert 100 pounds on a, and, therefore, 10,000 pounds on C.

Applications of this principle are seen in the hydraulic machines used for forcing locomotive drivers on their axles, etc., and for testing the strength of boiler-shells.

EXAMPLE.—A suspended vertical cylinder is tested for the tightness of its heads by filling it with water. A pipe whose inside diameter is $\frac{1}{4}$ of an inch, and whose length is 20 feet, is screwed into a hole in the upper head, and then filled with water; what is the pressure per square inch on each head, if the cylinder is 40 inches in diameter and 60 inches long?

SOLUTION.—Area of heads $= 40^2 \times .7854 = 1,256.64$ sq. in.

The pressure per square inch on the bottom head due to the weight of the water in the cylinder $= 1 \times 60 \times .03617 = 2.17$ pounds. $(\frac{1}{4})^2 \times .7854 = .04909$ sq. in., the area of the pipe.

$.04909 \times 20 \times 12 \times .03617 = .426$ pound = the weight of water in pipe = the pressure on a surface area of .04909 sq. in.

The pressure per square inch due to the water in the pipe is $\frac{1}{.04909} \times .426 = 8.68$ pounds per square inch upon the upper head. Ans.

The pressure per square inch on the lower head is $8.68 + 2.17 = 10.85$ pounds. Ans.

EXAMPLE.—In the last example, if the pipe be fitted with a piston weighing $\frac{1}{4}$ of a pound, and a 5-pound weight be laid upon it, what will be the pressure upon the upper head?

SOLUTION.—In addition to the pressure of .426 pound on the area of .04909 sq. in., there is now an additional pressure upon this area of $5 + \frac{1}{4} = 5.25$ pounds, and the total pressure upon this area is $.426 + 5.25 = 5.676$ pounds. Ans.

The pressure per square inch is $\frac{1}{.04909} \times 5.676 = 115.6$ pounds.

BUOYANT EFFECTS OF WATER.

2183. In Fig. 738 is shown a 6-inch cube, entirely submerged in water. The lateral pressures are equal and in opposite directions. The upward pressure $= 6 \times 6 \times 21 \times .03617$; the downward pressure $= 6 \times 6 \times 15 \times .03617$, and the difference $= 6 \times 6 \times 6 \times .03617$ = the volume of the cube in cubic inches × the weight of 1 cubic inch of water. That is, the upward pressure exceeds the downward pressure by the weight of a volume of water equal to the volume of the body.

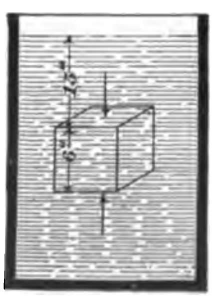


FIG. 738.

2184. This excess of upward pressure over the downward pressure acts against gravity; consequently, *if a body be immersed in a fluid, it will lose in weight an amount equal to the weight of the fluid it displaces.* This is called the **principle of Archimedes,** because it was first stated by him.

This principle may be experimentally demonstrated with the beam-scales, as shown in Fig. 739.

From one scale-pan suspend a hollow cylinder of metal *t*, and below that a solid cylinder *a*, of the same size as the hollow part of the upper cylinder. Put weights in the other scale-pan until they exactly balance the two cylinders. If *a* be immersed in water, the scale-pan containing the weights will descend, showing that *a* has lost some of its weight. Now, fill *t* with water, and the volume of water that can be poured into *t* will equal that displaced by *a*. The scale-pan that contains the weights will gradually rise until *t* is filled, when the scales balance again.

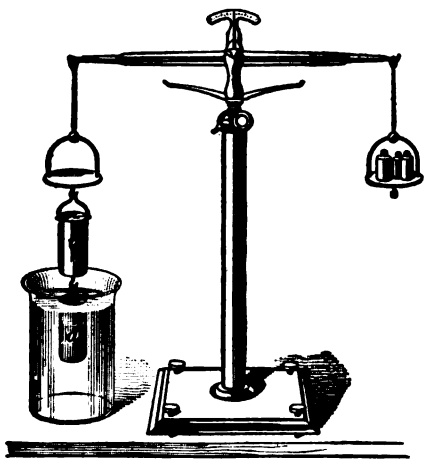


FIG. 739.

If the immersed body be lighter than the liquid, the upward pressure will cause it to rise and extend partly out of the liquid, until the weight of the body and the weight of the liquid displaced are equal. If the immersed body be heavier than the liquid, the downward pressure, plus the weight of the body, will be greater than the upward pressure, and the body will fall downwards, until it touches bottom or meets an obstruction. If the weights of equal volumes of the liquid and the body are equal, the body will remain stationary, and be in equilibrium in any position or depth beneath the surface of the liquid.

An interesting experiment in confirmation of the above

facts may be performed as follows: Drop an egg into a glass jar filled with fresh water. The mean density of the egg being a little greater than that of water, it will fall to the bottom of the jar. Now dissolve salt in the water, stirring it so as to mix the fresh and salt water. The salt water will presently become denser than the egg, and the egg will rise. Now, if fresh water be poured in until the egg and water have the same density, the egg will remain stationary in any position that it may be placed below the surface of the water.

HYDROKINETICS.

FLOW OF WATER THROUGH SHORT TUBES.

2185. Hydrokinetics, also called **hydrodynamics and hydraulics,** treats of water in motion. The velocity is not the same at all points of the flow, unless all cross-sections of the pipe or canal are equal. That *velocity* which, being *multiplied by the area of the cross-section of the stream*, will equal the total quantity *discharged* is called the **mean velocity.**

Let $Q =$ the quantity which passes any section in one second;
$A =$ the area of the section;
$v =$ the mean velocity in feet per second.

Then,
$$Q = A v, \qquad \textbf{(165.)}$$
and
$$v = \frac{Q}{A}. \qquad \textbf{(166.)}$$

EXAMPLE.—The area of a certain cross-section of a stream is 27.9 square inches; the velocity of the water through this section is 51 feet per second; what is the quantity discharged in cubic feet?

SOLUTION.—Applying formula **165**, $Q = \frac{27.9}{144} \times 51 = 9.9$ cubic feet per second. Ans.

EXAMPLE.—In the last example, what would the velocity have been to discharge the same quantity had the area of the cross-section been 36 square inches?

SOLUTION.—Applying formula **166,** $V = \frac{9.9}{\frac{36}{144}} = \frac{9.9 \times 144}{36} = 39.6$ ft. per sec. Ans.

2186. Velocity of Efflux.—If a small aperture be made in a vessel containing water, the velocity with which the water issues from the vessel is the same as if it had fallen from the level of the surface to the level of the aperture, all resistances being neglected. This velocity is called **the velocity of efflux.**

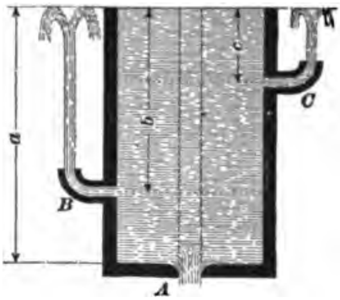


FIG. 740.

The vertical height of the level surface of the water above the center of the aperture is called the **head.** In Fig. 740, a is the head for the aperture A; b is the head for the aperture B; and c is the head for the aperture C.

Let v = the velocity of efflux in feet per second;

h = the head in feet at the aperture considered.

Then, the theoretical velocity of efflux is expressed by the formula

$$v = \sqrt{2gh}. \qquad \textbf{(167.)}$$

Here $g = 32.16$; that is, *the velocity of efflux is the same as if the same weight of water had fallen through a height equal to its head.*

Were it not for the resistance of the air, friction, and the effect of the falling particles, the issuing water would spout to the level of the water in the vessel; that is, to a height equal to its head.

EXAMPLE.—A small orifice is made in a pipe 50 feet below the water-level; what is the velocity of the issuing water?

SOLUTION.—Applying formula **167,** $v = \sqrt{2 \times 32.16 \times 50} = 56.7$ feet per second. Ans.

From the above formula, as in the laws of falling bodies,

$$h = \frac{v^2}{2g}. \qquad \textbf{(168.)}$$

Here, h is called the *head due to the velocity* v. Consequently, if the velocity of efflux is known, the head can be found.

EXAMPLE.—An issuing jet of water has a velocity of 60 feet per second; what must be the head to give it this velocity?

SOLUTION.—Applying formula **168**, $h = \frac{60^2}{2 \times 32.16} = 55.97$ feet. Ans.

2187. Suppose that a tall vessel is fitted with a piston, and has an orifice near the bottom fitted with a stop-cock. If an additional pressure be applied to the piston, it is evident that the velocity of efflux will be increased.

Let p be the pressure per unit of area at the level of the water, due to the additional pressure on the piston. If the unit of area is one square inch, the height of a column of water that would cause a pressure equal to p would be $\frac{p}{.434}$ feet.

If the unit of area is in square feet, the height of a column of water would be $\frac{p}{62.5}$ feet. Denote this height corresponding to the additional pressure by h_1. The original head of the water in the vessel is h; hence, $h_1 + h =$ the total head, and the velocity of efflux, when the cock is opened, will be

$$v = \sqrt{2g(h_1 + h)}. \qquad \textbf{(169.)}$$

The total head $h_1 + h$ is called the **equivalent head,** and must, in all cases, be reduced to feet before substituting in the formula.

EXAMPLE.—The area of a piston fitting a vessel filled with water is 27.36 square inches. The total pressure on the piston is 80 pounds; the weight of the piston is 25 pounds, and the head of the water at the level of the orifice is 6 feet 10 inches; what is the velocity of efflux, assuming that there are no resistances?

SOLUTION.— $80 + 25 = 105$ pounds = the total pressure on the upper surface of the liquid. $\frac{105}{27.36} = 3.838$ pounds per square inch.

$\frac{3.838}{.03617} = 106.11 =$ head in inches due to the pressure of 105 pounds.

$\frac{106.11}{12} = 8.84$ ft. $= h_1$. 6 feet 10 inches $= 6.8333$ feet $= h$.

Hence, applying formula **169**,

$v = \sqrt{2g(8.84 + 6.8333)} = \sqrt{2 \times 32.16 \times 15.6733} = 31.75$ feet per second. Ans.

2188. When water issues from the side of a vessel, it is subjected to the same laws that govern projectiles. The range may be calculated in the same manner by taking the *velocity of efflux* as the *initial velocity* of the projectile.

The range may be calculated more conveniently by the following formula:

$$R = \sqrt{4hy}, \qquad \textbf{(170.)}$$

in which R is the range, h is the head or equivalent head at the level of the orifice, and y is the vertical height of the orifice above the point where the water strikes. In Fig. 741, the upper surface of the water is free. For the orifice E, $h = BE$, and $y = EA$; for the orifice C, $h = BC$, and $y = CA$.

The greatest range is obtained when $h = y$; that is, when the orifice is half way between the upper surface of the water and the level of the place where the stream strikes.

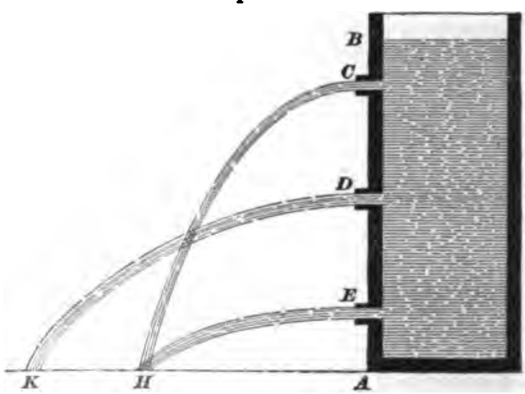


FIG. 741.

If two orifices are situated equally distant from the middle orifice, giving the greatest range, as C and E in Fig. 741, the ranges of water issuing from them will be equal.

EXAMPLE.—The vertical height above the ground of the surface of the water in a vessel is 12 feet. If an orifice is situated 4 feet from

the upper surface, what is the range? Where is the other point of equal range? What is the greatest range?

SOLUTION.—Applying formula **170**, $R = \sqrt{4 \times 4\,(12 - 4)} = 11.31$ feet, nearly; greatest range $= \sqrt{4 \times 6 \times 6} = 12$ feet. $6 - 4 = 2$; hence, the point of equal range is $6 + 2 = 8$ feet below the surface of the water. Ans.

PROOF.—Range $= \sqrt{4\,h\,y} = \sqrt{4 \times 8 \times 4} = 11.31$ feet as before.

2189. When the water flows through an orifice in the bottom of the vessel, of large size compared with the area of the base, a different rule must be used from that given above. In Fig. 742, suppose that the area of the orifice in the bottom of the vessel is a, and that the area of the bottom is A; then the velocity v is expressed by the formula

$$v = \sqrt{\frac{2gh}{1 - \frac{a^2}{A^2}}}. \qquad \textbf{(171.)}$$

FIG. 742.

That is, *the velocity of efflux from the bottom of a vessel in feet per second equals the square root of $2g$ times the head, divided by 1, minus the ratio of the square of the area of the orifice, to the square of the area of the bottom.*

If the area of the orifice is not more than $\frac{1}{20}$ of the area of the cross-section of the vessel, use formula **167**. That is, *the velocity of efflux from a small orifice, not larger than $\frac{1}{20}$ of the cross-sectional area of the vessel, equals the square root of $2g$ times the head.*

EXAMPLE.—A vessel has a rectangular cross-section of 11×14 inches; the upper surface of the water is 14 feet above the bottom. If an orifice, 4 inches square, is made in the bottom of the vessel, what will be the velocity of efflux?

SOLUTION.—Area of the cross-section is $14 \times 11 = 154$ sq. in. Area of orifice is $4 \times 4 = 16$ sq. in., $\frac{16}{154} = \frac{1}{9.625}$. Since the area of the orifice is greater than $\frac{1}{20}$ of the area of the bottom, apply formula **171**.

$$v = \sqrt{\frac{2gh}{1 - \frac{a^2}{A^2}}} = \sqrt{\frac{2 \times 32.16 \times 14}{1 - \frac{16^2}{154^2}}} = 30.17 \text{ feet per second. Ans.}$$

Example.—If the orifice had been 2 inches square in the above example, what would have been the velocity of efflux? Also, if it had been 8 inches square?

Solution.— $2 \times 2 = 4$ sq. in., or the area of the orifice. $\frac{4}{154} = \frac{1}{38.5}$. Since the area of the orifice is less than $\frac{1}{10}$ of the area of the vessel, apply formula **167**,

$$v = \sqrt{2gh} = \sqrt{2 \times 32.16 \times 14} = 30.008 \text{ feet per second. Ans.}$$

$8 \times 8 = 64$ sq. in., or the area of the orifice in the second case; then, applying formula **171**,

$$v = \sqrt{\frac{2gh}{1 - \frac{a^2}{A^2}}} = \sqrt{\frac{2 \times 32.16 \times 14}{1 - \frac{64^2}{154^2}}} = 32.99 \text{ feet per second; practically, 33 feet per second. Ans.}$$

2190. The Contracted Vein.—When water issues from an orifice in a thin plate (see Fig. 743), or from a square-edged orifice (see Fig. 744), the stream is contracted a short distance from the orifice, and expands again to the full size of the orifice. The point at which the contraction is greatest is at a distance from the orifice equal to the diameter of the orifice. In consequence of this contraction, the velocity of efflux is slightly reduced from the theoretical value, and the quantity discharged is greatly reduced. This contraction is called the **contracted vein,** a name given to it by Sir Isaac Newton.

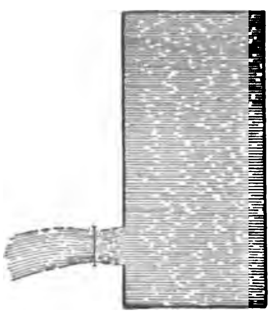


Fig. 743.

For ordinary purposes, the actual velocity of efflux may be taken as 98% of the theoretical values calculated by the preceding rules.

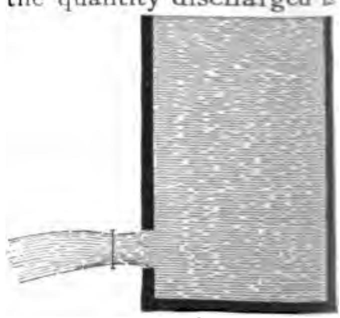


Fig. 744.

The actual velocity of efflux from a small orifice is expressed by the formula

$$v = .98\sqrt{2gh}. \qquad (172.)$$

EXAMPLE.—What is the actual velocity of discharge from a small, square-edged orifice in the side of a vessel, if the head is 20 feet?

SOLUTION.—Applying formula **172**,

$v = .98\sqrt{2gh} = .98\sqrt{2 \times 32.16 \times 20} = 35.15$ feet per second. Ans.

2191. The diameter of the contracted vein at its smallest section is about .8 of the diameter of the orifice, and its area is about $.8 \times .8 = .64$ of the area of the orifice. In Art. **2185**, it was stated that the quantity discharged in cubic feet per second was equal to the area of the section multiplied by the mean velocity, or $Q = A\,v$. This was the theoretical value; *the actual value is the area of the contracted vein multiplied by the actual velocity of efflux*, or $Q = .64\,A \times .98\,v = .627\,A\,v$; that is, the actual discharge is about .627 of the theoretical discharge.

This number, .627, is called the **coefficient of efflux.**

The coefficient of efflux varies somewhat according to the head, and the size and shape of the orifice; but for square-edged orifices, or for orifices in thin plates, its average value may be taken as .615. Hence,

Rule.—*The actual quantity discharged is .615 times the theoretical amount*,

or, $$Q = .615\,A\,v. \quad \textbf{(173.)}$$

EXAMPLE.—The theoretical discharge from a certain vessel is 12.4 cubic feet per minute; what is the amount actually discharged per second?

SOLUTION.— $12.4 \times .615 = 7.626$ cubic feet per minute; $\frac{7.626}{60} =$ .1271 cubic foot per second. Ans.

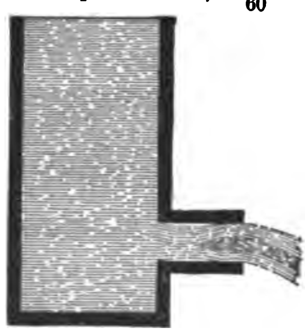


FIG. 745.

2192. If the water discharges through a short tube whose length is from $1\frac{1}{2}$ to 3 times the diameter of the orifice (see Fig. 745), the discharge is increased. From a large number of experiments made by different persons, the coefficient of efflux for a short tube may be taken as .815; that is, the actual discharge may be taken

as .815 times the theoretical discharge through an orifice of the same size. If the inside edges of the tube are well rounded, and the tube is conical, as shown in Fig. 746, there will be no contraction, and the coefficient of discharge may be taken as .97; that is, the actual discharge through a tube of this form is .97 times the theoretical discharge through an orifice whose area is the same as the area of the end of the tube.

FIG. 746.

2193. If in a compound mouthpiece or tube, such as is shown in Fig. 747, *a b*, the narrowest part, be taken as the diameter of the orifice, the coefficient of discharge may be taken as 1.5526; that is, the actual discharge through a compound mouthpiece of this shape is 1.5526 times the theoretical discharge through an orifice whose area is the same as the area of the smallest section of the mouthpiece.

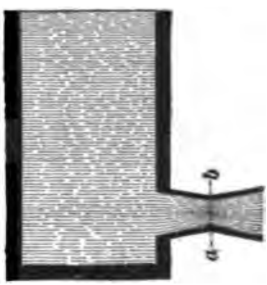


FIG. 747.

2194. When the upper surface of the water remains at the same height above the orifice, there is said to be a *constant head.* The velocity of efflux varies for different points in the orifice; it is greater at the bottom of the orifice than at the top, since the head is greater at the bottom than at the top. A mean velocity may be obtained by *dividing the quantity of water discharged in cubic feet per second by the area of the orifice;*

or, $$v_m = \frac{Q}{A}. \quad \text{(See formula } \mathbf{166.}\text{)}$$

2195. Let

Q = theoretical number of cubic feet discharged per second;

v_m = mean velocity through orifice;

A = area of orifice;

h = theoretical head necessary to give a mean velocity v_m;

Q_a = actual quantity discharged in cubic feet per second.

Then, for an orifice in a thin plate, or a square-edged orifice (the hole itself may be of any shape—triangular, square, circular, etc.—but the edges must not be rounded), the actual quantity discharged is

$$\begin{aligned} Q_a &= .615\, Q, \text{ or} \\ &= .615\, A\, v_m, \text{ or} \\ &= .615\, A \sqrt{2 g h}. \end{aligned} \qquad \textbf{(174.)}$$

That is, *the actual quantity discharged through a square-edged orifice, or through a thin plate, is .615 times the theoretical discharge, and equals .615 multiplied by the area of the orifice, multiplied by the mean velocity; or equals .615 multiplied by the area of the orifice, multiplied by the square root of 2 g times the theoretical head, corresponding to the theoretical mean velocity.*

For a discharge through a short tube, as shown in Fig. 745,

$$Q_a = .815\, Q = .815\, A\, v_m = .815\, A \sqrt{2 g h}. \qquad \textbf{(175.)}$$

For a discharge through a mouthpiece, as shown in Fig. 746,

$$Q_a = .97\, Q = .97\, A\, v_m = .97\, A \sqrt{2 g h}. \qquad \textbf{(176.)}$$

For a discharge through the compound mouthpiece, as shown in Fig. 747, the area of the orifice being taken as the area of the smallest section,

$$Q_a = 1.5526\, Q = 1.5526\, A\, v_m = 1.5526\, A \sqrt{2 g h}. \qquad \textbf{(177.)}$$

In these four formulas it is assumed that the head remains constant.

WEIRS.

2196. The **weir** is a device universally used for measuring the discharge of water. It is a rectangular orifice through which the water flows.

2197. In Fig. 748 is represented a weir in which the top of the weir (orifice) is level with the upper surface of the water flowing through it. By means of higher mathematics, it has been found that the *theoretical mean velocity* v_m is equal to $\frac{2}{3}\sqrt{2\,g\,h}$.

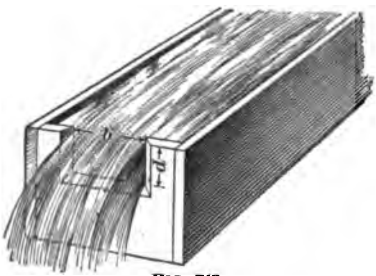


FIG. 748.

2198. If $d =$ the depth of the opening in feet, and b its breadth in feet, the area of the opening $A = d\,b$, and the theoretical discharge is $Q = d\,b\,v_m = \frac{2}{3}\,d\,b\sqrt{2\,g\,d}$, the head for this case being taken as d.

The actual discharge is

$$Q_a = .615\,Q = .615\,d\,b \times \tfrac{2}{3}\sqrt{2\,g\,d} = .41\,b\sqrt{2\,g\,d^3}. \qquad \textbf{(178.)}$$

That is, *the actual discharge through a weir in cubic feet per second, whose top is on a level with the upper surface of the water, is equal to .41 multiplied by the breadth of the weir, multiplied by the square root of 2g times the cube of the depth of the weir.* All dimensions are to be taken in feet.

EXAMPLE.—A weir like the one represented in Fig. 748 has a depth $d = 18$ inches, and a breadth $b = 30$ inches; what is the actual discharge per minute in cubic feet?

SOLUTION.—Applying formula **178**,

$Q_a = .41 b\sqrt{2\,g\,d^3} = .41 \times \frac{30}{12} \times \sqrt{2 \times 32.16 \times (\frac{18}{12})^3} = 15.1$ cubic feet per second.
$15.1 \times 60 = 906$ cubic feet per minute. Ans.

2199. To obtain the mean velocity v_m, divide the actual discharge by the area of the weir.

Thus,
$$v_m = \frac{Q_a}{A} = \frac{Q_a}{b\,d}. \qquad \textbf{(179.)}$$

EXAMPLE.—What is the mean velocity in feet per second of the water in the last example?

SOLUTION.—Applying formula **179**,

$$v_m = \frac{Q_a}{b\,d} = \frac{15.1}{2\frac{1}{2} \times 1\frac{1}{2}} = \frac{15.1}{3.75} = 4.027 \text{ feet per second. Ans.}$$

2200. It should be kept in mind that a weir is but a rectangular opening. It is a special name given to a rectangular orifice. Some writers use the term **rectangular notch** instead of weir.

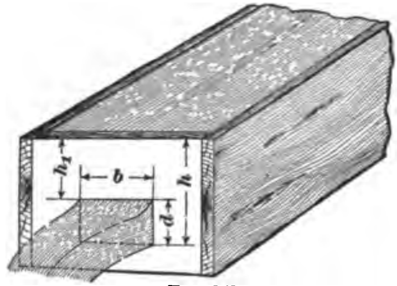


FIG. 749.

2201. In Fig. 749 is represented a weir whose top is below the level of the upper surface of the water. If h_1 is the depth in feet of the top of the weir below the surface of the water, and h is the depth in feet of the bottom of the weir below the surface of the water, the actual discharge Q_a in cubic feet per second is

$$Q_a = .41\, b\sqrt{2g}\left[\sqrt{h^3} - \sqrt{h_1^3}\right]. \qquad \textbf{(180.)}$$

That is, *the actual discharge through a weir, whose top is h_1 feet, and whose bottom is h feet, below the surface of the water, is equal to .41 times the breadth of the weir multiplied by the square root of 2 g times the difference of the square roots of the cubes of the depth of the bottom of the weir, and the depth of the top of the weir.*

EXAMPLE.—A weir like that shown in Fig. 749 has a depth $d = 2$ feet, and a breadth $b = 3$ feet. The depth of the top below the surface of the water is 5 feet; what is the discharge in cubic feet per minute?

SOLUTION.— $h_1 = 5$. $h = 5 + 2 = 7$. Hence, applying formula **180**,

$$Q_a = .41\, b\sqrt{2g}\left[\sqrt{h^3} - \sqrt{h_1^3}\right] =$$

$.41 \times 3 \times \sqrt{2 \times 32.16} \times \left[\sqrt{7^3} - \sqrt{5^3}\right] = 72.41$ cubic feet per second $=$ $72.41 \times 60 = 4{,}344.6$ cubic feet per minute. Ans.

EXAMPLE.—What is the mean velocity in the last example?

SOLUTION.—Applying formula **179**,

$$v_m = \frac{Q_a}{b\,d} = \frac{72.41}{2 \times 3} = 12.07 \text{ feet per second. Ans.}$$

FLOW OF WATER IN PIPES.

LOSS DUE TO FRICTION.

2202. When water flows from one reservoir to another through a pipe, the velocity of efflux is considerably less than the theoretical velocity due to the head. This loss is

due to several causes, but is principally caused by the friction of the water against the inside surface of the pipe. *This friction varies directly as the length of the pipes, and inversely as the diameter;* that is, the friction in a pipe 200 feet long is twice as much as in a pipe 100 feet long, and the friction in a pipe 4 inches in diameter is only half as much as in a pipe 2 inches in diameter, the velocity remaining the same in both cases. *The friction also varies with the velocity.*

MEAN VELOCITY OF DISCHARGE.

2203. The following formulas apply to straight cylindrical pipes of uniform diameter:

Let v_m = mean velocity of discharge in feet per second;
h = total head in feet = the vertical distance between the level of the water in the reservoir and the point of discharge;
l = length of pipe in feet;
d = diameter of pipe in inches;
f = coefficient of friction.

Then, for straight cylindrical pipes of uniform diameter, the mean velocity of efflux may be calculated by the formula

$$v_m = 2.315 \sqrt{\frac{h\,d}{f\,l + .125\,d}}. \qquad \textbf{(181.)}$$

That is, *the mean velocity of discharge equals 2.315 times the square root of the head in feet, multiplied by the diameter in inches, divided by the coefficient of friction, multiplied by the length in feet, plus .125 of the diameter of the pipe in inches.*

The head is always taken as the vertical distance between the point of discharge and the level of the water at the source, or point from which it is taken, and is always measured in feet. It matters not how long the pipe is, whether vertical or inclined, whether straight or curved, nor whether any part of the pipe goes below the level of the point of discharge, the head is always measured as stated above.

EXAMPLE.—What is the mean velocity of efflux from a 6-inch pipe 5,780 feet long, if the head is 170 feet? Take $f = .021$.

SOLUTION.—Applying formula **181**,

$$v_m = 2.315\sqrt{\frac{h\,d}{f\,l + .125\,d}} = 2.315\sqrt{\frac{170 \times 6}{.021 \times 5{,}780 + (.125 \times 6)}} = 6.69$$

feet per second. Ans.

2204. When the pipe is very long, compared with the diameter, as in the above example, the following formula may be used:

$$v_m = 2.315\sqrt{\frac{h\,d}{f\,l}}, \qquad \textbf{(182.)}$$

in which the letters have the same meaning as in the preceding formula. This formula may be used when the length of the pipe exceeds 10,000 times its diameter.

EXAMPLE.—In the preceding example, calculate the value of v_m by using formula **182.**

SOLUTION.—

$$v_m = 2.315\sqrt{\frac{h\,d}{f\,l}} = 2.315\sqrt{\frac{170 \times 6}{.021 \times 5{,}780}} = 6.71 \text{ feet per second. Ans.}$$

THE ACTUAL HEAD.

2205. The **actual head** necessary to produce a certain velocity v_m may be calculated by the formula

$$h = \frac{f\,l\,v_m^2}{5.36\,d} + .0233\,v_m^2. \qquad \textbf{(183.)}$$

That is, *the total head in feet necessary to produce a velocity of efflux v_m in a straight cylindrical pipe is equal to the coefficient of friction multiplied by the length of the pipe in feet, multiplied by the square of the mean velocity of efflux in feet per second, divided by 5.36 times the diameter of the pipe in inches, plus .0233 times the square of the mean velocity.*

EXAMPLE.—A 7-inch pipe 6,000 feet long is required to deliver water with a velocity of 7 feet per second; what must be the necessary head? Assume $f = .026$.

SOLUTION.—Applying formula **183**,

$$h = \frac{f l v_m^2}{5.36 d} + .0233\, v_m^2 = \frac{.026 \times 6{,}000 \times 49}{5.36 \times 7} + .0233 \times 49 = 204.87 \text{ feet,}$$

nearly. Ans.

THE QUANTITY DISCHARGED FROM PIPES.

2206. The formulas just given are made use of in ascertaining the quantity of water that will be discharged from a pipe in a given time with a given head. This is readily found by substituting the value of v_m for v in formula **165**; thus, $Q = A\, v_m$.

Since $A = .7854\, d^2$ = area of the inside of the pipe, the quantity discharged can be readily calculated as soon as v_m is known. This method gives the discharge in cubic feet per second, when the diameter d is taken in feet.

One cubic foot contains 7.48 gallons; hence, when d is taken in feet,

$$Q = .7854\, d^2\, v_m \times 7.48 \text{ gallons.}$$

If d is taken in inches,

$$Q = \frac{.7854\, d^2}{144} v_m \times 7.48;$$

or,

$$Q = .0408\, d^2\, v_m. \qquad \textbf{(184.)}$$

That is, *the discharge in gallons per second equals .0408 times the square of the diameter of the pipe in inches, multiplied by the mean velocity of efflux in feet per second.*

EXAMPLE.—What is the discharge in gallons per minute from a 6-inch pipe, if the mean velocity of efflux is 5.6 feet per second?

SOLUTION.—Applying formula **184**,

$$Q = .0408 d^2\, v_m = .0408 \times 36 \times 5.6 = 8.225 \text{ gallons per second.}$$
$$8.225 \times 60 = 493.5 \text{ gallons per minute. Ans.}$$

2207. If the diameter of the pipe and the discharge are known, the mean velocity can be readily found by the formula

$$v_m = \frac{24.51\, Q}{d^2}. \qquad \textbf{(185.)}$$

That is, *the mean velocity of discharge equals 24.51 times the number of gallons discharged per second, divided by the square of the diameter of the pipe in inches.*

EXAMPLE.—A 5-inch pipe is discharging 360 gallons per minute; what is the mean velocity of efflux?

SOLUTION.— $\frac{360}{60} = 6$ gallons discharged per second. Hence, applying formula **185**,

$$v_m = \frac{24.51 \times Q}{d^2} = \frac{24.51 \times 6}{25} = 5.882 \text{ feet per second. Ans.}$$

2208. If the head, the length of the pipe, and the diameter of the pipe are given, to find the discharge, use the formula

$$Q = .09445\, d^2 \sqrt{\frac{h\, d}{f\, l + .125\, d}}. \qquad \textbf{(186.)}$$

That is, *the discharge in gallons per second equals .09445 times the square of the diameter of the pipe in inches, multiplied by the square root of the head in feet times the diameter of the pipe in inches, divided by the coefficient of friction times the length of the pipe in feet, plus .125 times the diameter of the pipe in inches.*

2209. To find the value of f, calculate v_m by formula **182**, assuming that $f = .025$, and get the final value of f from the following table:

TABLE 45.

$v_m =$	0.1	0.2	0.3	0.4	0.5	0.6
$f =$	.0686	.0527	.0457	.0415	.0387	.0365
$v_m =$	0.7	0.8	0.9	1	$1\frac{1}{4}$	$1\frac{1}{2}$
$f =$	.0349	.0336	.0325	.0315	.0297	.0284
$v_m =$	2	3	4	6	8	12
$f =$	.0265	.0243	.023	.0214	.0205	.0193

EXAMPLE.—The length of a pipe is 6,270 feet, its diameter is 8 inches, and the total head at the point of discharge is 215 feet; how many gallons are discharged per minute?

SOLUTION.—Using formula **182**,

$$v_m = 2.315\sqrt{\frac{h\,d}{f\,l}} = 2.315\sqrt{\frac{215 \times 8}{.025 \times 6{,}270}} = 7.67 \text{ feet per second, nearly.}$$

For $v_m = 6, f = .0214$, and for $v_m = 8, f = .0205$.

$.0214 - .0205 = .0009$ = difference for a difference in the v_m's of 2 ft. per sec.

$.0009 \div 2 = .00045$ = difference for a difference in the v_m's of 1 ft. per sec.

$7.67 - 6 = 1.67$. $.00045 \times 1.67 = .0007515$ = amount to be subtracted from .0214 to obtain f for $v_m = 7.67$. Using but five decimal places, $.0214 - .00075 = .02065 = f$ for $v_m = 7.67$.

Hence, applying formula **186**,

$$Q = .09445\,d^2\sqrt{\frac{h\,d}{f\,l + .125\,d}} = .09445 \times 8^2\sqrt{\frac{215 \times 8}{.02065 \times 6{,}270 + .125 \times 8}} =$$

21.95 gallons per second, nearly.

$21.95 \times 60 = 1{,}317$ gallons per minute. Ans.

2210. If it is desired to find the head necessary to give a discharge of a certain number of gallons per second through a pipe whose length and diameter are known, calculate the mean velocity of efflux by using formula **185.** Find the value of f from Table 45, corresponding to this value of v_m; substitute these values of f and v_m in formula **183,** and calculate the head.

EXAMPLE.—A 4-inch pipe, 2,000 feet long, is to discharge 24,000 gallons of water per hour; what must be the head?

SOLUTION.— $\frac{24{,}000}{60 \times 60} = 6\frac{2}{3}$ gallons per second. Using formula **185,**

$$v_m = \frac{24.51\,Q}{d^2} = \frac{24.51 \times 6\frac{2}{3}}{16} = 10.2 \text{ feet per second.}$$

In Table 45, $f = .0205$ for $v_m = 8$, and .0193 for $v_m = 12$.

$.0205 - .0193 = .0012$ = difference for a difference in the mean velocities of 4 ft. per sec. $.0012 \div 4 = .0003$ = difference for a difference of 1 ft. per sec. $10.2 - 8 = 2.2$. $.0003 \times 2.2 = .00066$. $.0205 - .00066 = .01984$. Then, substituting in formula **183,**

$$h = \frac{f\,l\,v_m^2}{5.36\,d} + .0233\,v_m^2 = \frac{.01984 \times 2{,}000 \times 10.2^2}{5.36 \times 4} + .0233 \times 10.2^2 = 195 \text{ ft.}$$

Ans.

BENDS AND ELBOWS.

2211. In laying pipes, all bends and elbows should be avoided as much as possible. When they are absolutely necessary, they should be as large as the circumstances will

permit, so as to change the direction gradually. Sudden changes in direction destroy the velocity very rapidly, and,

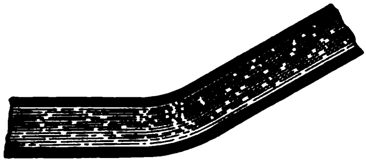


FIG. 750.

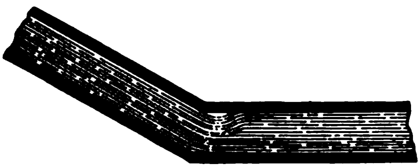


FIG. 751.

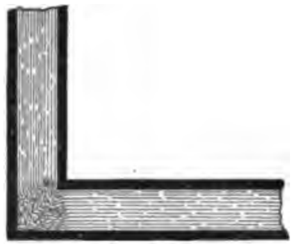


FIG. 752.

consequently, reduce the discharge. A reduction or increase in the size of the pipe, owing to the screwing on of branch pipes smaller or larger than the main pipe, also reduces the velocity.

When bends are necessary, it is better to round them, as shown in Fig. 750, than to have a sharp bend, as shown in Fig. 751. A bend at right angles, as shown in Fig. 752, is very destructive to the velocity. A rounded elbow, as shown in Fig. 753, should be used, in which the radius should be made as large as possible.

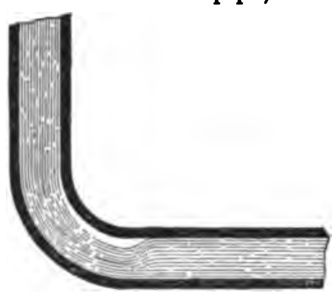


FIG. 753.

PUMPS.

DESCRIPTION OF TYPES.

2212. The Suction-Pump.—A section of an ordinary suction-pump is shown in Fig. 754. Suppose the piston to be at the bottom of the cylinder, and to be just on the point of moving upwards in the direction of the arrow. As

the piston rises, it leaves a vacuum behind it; the atmospheric pressure upon the surface of the water in the well causes it to rise in the pipe P, for the same reason that the mercury rises in the barometer-tube. The water rushes up the pipe, and lifts the valve V, filling the empty space in the cylinder B, displaced by the piston. When the piston has reached the end of its stroke, the water entirely fills the space between the bottom of the piston and the bottom of the cylinder, and also the pipe P. The instant that the piston begins its down stroke,

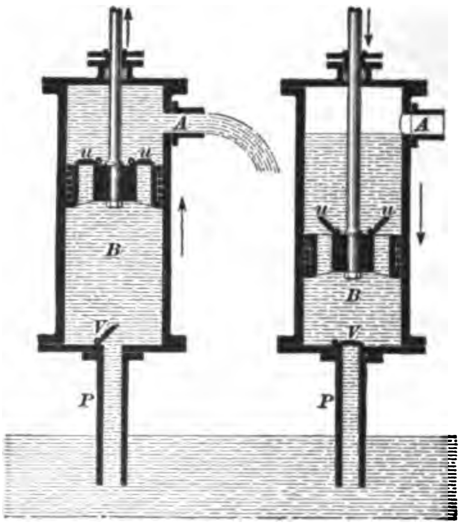


FIG. 754.

the water in the chamber B tends to fall back into the well, and its weight forces the valve V to its seat, thus preventing any downward flow of the water. The piston now tends to compress the water in the chamber B; but this is prevented by the opening of the valves u, u in the piston. When the piston has reached the end of its downward stroke, the weight of the water above closes the valves u, u. All the water resting on the top of the piston is then lifted with the piston on its upward stroke, and discharged through the spout A, the valve V again opening, and the water filling the space below the piston as before.

It is evident that the distance between the valve V and the surface of the water in the well must not exceed 34 feet, the highest column of water which the pressure of the atmosphere will sustain, since, otherwise, the water in the pipe would not reach to the height of the valve V. In practice, this distance should not exceed 28 feet, or, to obtain the best

effects, not more than 22 feet. This is due to the fact that there is a little air left between the bottom of the piston and the bottom of the cylinder; a little air leaks through the valves, which are not perfectly air-tight, and a pressure is needed to raise the valve against its weight, which, of course, acts downwards. There are many varieties of the suction-pump, differing principally in the valves and piston; but the principle is the same in all.

2213. The Lifting-Pump.—A section of a lifting-pump is shown in Fig. 755. These pumps are used when water is to be raised to greater heights than can be done with the ordinary suction-pump. As will be perceived, it is essentially the same as the pump previously described, except that the spout is fitted with a cock, and has a pipe attached to it, leading to the point of discharge. If it is desired to discharge the water at the spout, the cock may be opened; otherwise, the cock is closed, and the water is lifted by the piston up through the pipe P' to the point of discharge, the valve c preventing it from falling back into the pump, and the valve V preventing the water in the pump from falling back into the well. It is not necessary that there should be a second pipe P', as shown in the figure, for the pipe P may be continued straight upwards.

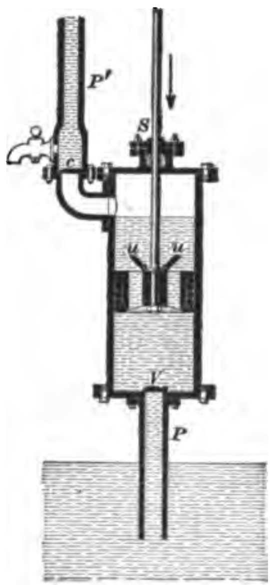


FIG. 755.

In all pumps, the pipe that conducts the water or other liquid to the pump-cylinder is called the **suction-pipe**; the pipe that conducts the water away from the pump-cylinder is called the **delivery** or **discharge pipe.** In Figs. 755 and 756, P is the suction and P' the delivery pipe. The suction-pipe is sometimes called the **inlet-pipe.**

2214. Force-Pumps.—The force-pump differs from the lifting-pump in several important particulars, but chiefly in the fact that the piston is solid; that is, it has no valves. A section of a suction and force pump is shown in Fig. 756. The water is drawn up the suction-pipe *P*, as before, when the piston rises; but, when the piston reverses, the pressure on the water caused by the descent of the piston opens the valve *V'*, and *forces* the water up the delivery-pipe *P'*. When the piston again begins its upward movement, the valve *V'* is closed by the pressure of the water above it, and the valve *V* is opened by the pressure of the atmosphere on the water below it, as in the previous cases. For an arrangement of this kind, it is not necessary to have a stuffing-box. The water may be forced to almost any desired height. The force-pump differs again from the lifting-pump in respect to its piston-rod, which should not be longer than is absolutely necessary in order to prevent it from *buckling*, while in the lifting-pump the length of the piston-rod is a matter of indifference.

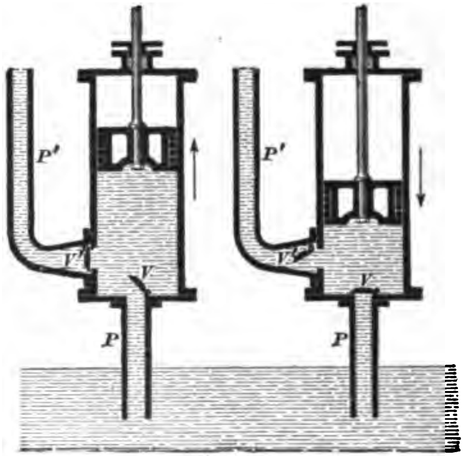


FIG. 756.

2215. Double-Acting Pumps.—In the pumps previously described, the discharge was intermittent; that is, the pump could only discharge when the piston was moving in one direction. In some cases, it is necessary that there should be a continuous discharge; in all cases, it takes more power to run the pump with an intermittent discharge, as a little consideration will show. If the height to which the water is to be raised is considerable, its weight will be very

great, and the entire mass must be put in motion during one stroke of the piston.

In order to obtain the advantage of a more continuous discharge, double-acting pumps are used. Fig. 757 shows a part sectional view of such a pump. Two pistons *a* and *b* are used, which are operated by one handle *c*, in the manner

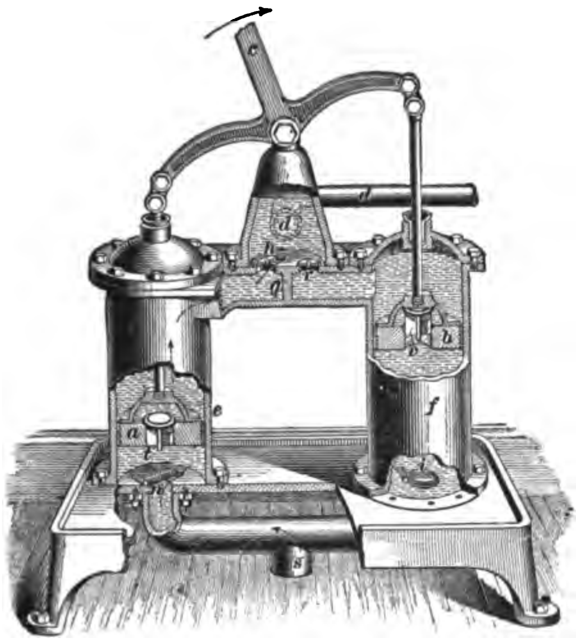


FIG. 757.

shown. The pump has one suction-pipe *s* and one discharge-pipe *d*. The cylinders *e* and *f* are separated by a diaphragm *g*, so that they can not communicate with each other above the pistons. In the figure, the handle *c* is moving to the right, the piston *a* upwards, and the piston *b* downwards. As the piston *a* moves upwards, it lifts the water above it, and causes it to flow through the delivery-valve *h* into the discharge-pipe *d*. This upward movement of the piston creates a partial vacuum below it in the cylinder *e*, and causes the water to rush up the suction-pipe *s* into the

cylinder, as shown by the arrows. In the cylinder *f*, the downward movement of the piston *b* raises the piston-valve *v*, and the weight of the water on the suction-valve *i* keeps it closed. When the handle *c* has completed its movement to the right, and begins its return, all the valves on the right-hand side open except *v*, and those on the left-hand side close except *t*; water is then discharged into the delivery-pipe by the cylinder *f*, and only at the instant of reversal is the flow into the delivery-pipe *d* stopped.

2216. Air-Chambers.—In order to obtain a continuous flow of water in the delivery-pipe, with as nearly a uniform velocity as possible, an **air-chamber** is usually placed on the delivery-pipe of force-pumps as near to the pump-cylinder as the construction of the machine will allow. The air-chambers are usually pear-shaped, with the small end connected to the pipe. They are filled with air which the water compresses during the discharge. During the suction, the air thus compressed expands, and acts as an accelerating force upon the moving column of water, a force which diminishes with the expansion of the air, and helps to keep the velocity of the moving column more nearly uniform. An air-chamber is sometimes placed upon the suction-pipe. These air-chambers not only tend to promote a uniform discharge, but also to equalize the stresses upon the pump, and prevent shocks due to the incompressibility of water. They serve the same purpose in pumps that a fly-wheel does to the steam-engine. Unless the pump moves very slowly, it is absolutely necessary to have an air-chamber on the delivery-pipe.

2217. Steam-Pumps.—Steam-pumps are force-pumps operated by steam acting upon the piston of a steam-engine directly connected to the pump, and, in many cases, cast with the pump. A section of a double-acting steam-pump showing the steam and water cylinders, with other details, is illustrated in Fig. 758. Here *G* is the steam-piston, and *R* the piston-rod, which is secured at its other end to the pump-plunger *P*. *F* is a partition cast with the

cylinder, which prevents the water in the left-hand half from communicating with that in the right-hand half of the cylinder. Suppose the piston to be moving in the direction indicated by the arrow. The volume of the left-hand half of the pump-cylinder will be increased by an amount equal to the area of the circumference of the plunger, multiplied by the length of the stroke, and the volume of the right-hand half of the cylinder will be diminished by a like amount. In consequence of this, a volume of water in the

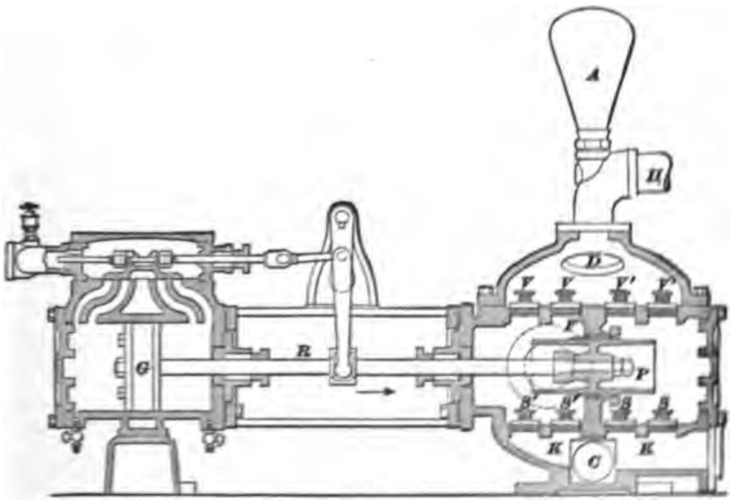


FIG. 734.

right-hand half of the cylinder equal to the volume displaced by the plunger in its forward movement will be forced through the valves V', V' into the air-chamber A, through the orifice D, and then discharged through the delivery-pipe H. By reason of the partial vacuum in the left-hand half of the pump-cylinder, owing to this movement of the plunger, the water will be drawn from the reservoir through the suction-pipe C into the chamber K K, lifting the valves S', S', and filling the space displaced by the plunger. During the return stroke, the water will be drawn through the valves S, S into the right-hand half of the pump-cylinder, and discharged through the valves V, V

in the left-hand half. Each one of the four suction and four discharge valves is kept to its seat when not working by light springs, as shown.

There are many varieties and makes of steam-pumps, the majority of which are double-acting. In many cases, two steam-pumps are placed side by side, having a common delivery-pipe. This arrangement is called a **duplex pump.** It is usual to so set the steam-pistons of duplex pumps, that when one is completing the stroke, the other is in the middle of its stroke. A double-acting duplex pump made to run in this manner, and having an air-chamber of sufficient size, will deliver water with nearly a uniform velocity.

In mine-pumps for forcing water to great heights, the plungers are made solid, and in most cases extend through the pump-cylinder. In many steam-pumps, pistons are used instead of plungers; but, when very heavy duty is required, plungers are to be preferred.

2218. Centrifugal Pumps.—Next to the direct-acting steam-pump, the centrifugal pump is the most valuable instrument for raising water to great heights that has yet been described. As the name denotes, the effects produced by centrifugal force are made use of. Fig. 759 represents one with half of the casing removed. The hub S is hollow, and is connected directly to the suction-pipe. The curved arms a, called **vanes,** or **wings,** are revolved with a high velocity in the direction indicated by the arrow, and the air enclosed between them is driven out through the discharge-

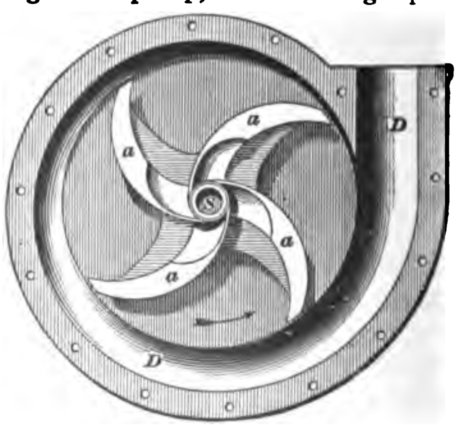


FIG. 759.

passage and delivery-pipe *D D*. This creates a partial vacuum in the casing and suction-pipe, and causes the water to flow in through *S*. This water is also made to revolve with the vanes, and, of course, with the same velocity. The centrifugal force of the revolving water causes it to fly outwards towards the end of the vanes, and becomes greater the farther away it gets from the center. This causes it to leave the vanes, and, finally, to leave the pump by means of the discharge-passage and delivery-pipe *D D*. The height to which the water can be forced depends upon the velocity of the revolving vanes. In the construction of the centrifugal pump, particular care is exercised in giving the correct form to the vanes; the efficiency of the machine depends greatly upon this point being attended to. What is required is to raise the water; and the energy used to drive the pump should be devoted as far as possible to this one purpose. The water, when it is raised, should be delivered with as little velocity as possible; for any velocity which the water then possesses has been produced at the expense of the energy used to drive the pump. The form of the vanes is such that the velocity with which the water leaves the pump is reduced to an amount just sufficient for its delivery at the proper height.

The number of vanes depends upon the size and capacity of the pump. It will be noticed that in the pump shown in the figure, the vanes have sharp edges near the hub. The object of this is to provide for a free ingress of the water, and also to cut any foreign substance that may enter the pump, and prevent it from working properly.

Centrifugal pumps are sometimes used to raise water 100 feet or more, but they work much more economically for heights of 25 to 40 feet. Almost any liquid can be raised with these pumps; but, when used for pumping chemicals, the casing and vanes are made of materials that the chemicals will not affect.

Mud, gravel, etc., can also be raised when mixed with water, the wear due to these impurities being very slight.

POWER REQUIRED FOR PUMPS.

2219. Rule.—In all pumps, whether lifting, force, steam, single or double-acting, or centrifugal, *the number of foot-pounds needed to work the pump is equal to the weight of the water in pounds, multiplied by the vertical distance in feet between the level of the water in the well, or source, and the point of discharge, plus the work necessary to overcome the friction and other resistances.*

2220. Rule.—*The work done in one stroke of a pump is equal to the weight of a volume of water equal to the volume displaced by the piston during the stroke, multiplied by the total vertical distance in feet through which the water is to be raised, plus the work necessary to overcome the resistances.*

2221. A little consideration will make this evident. Suppose that the height of the suction is 25 feet; that the vertical distance between the suction-valve and the point of discharge is 100 feet; that the stroke of the piston is 15 inches, and its diameter is 10 inches. Let the diameters of the suction-pipe and delivery-pipe be 4 inches each. The volume displaced by the pump piston or plunger in one stroke equals

$$\frac{10^2 \times .7854 \times 15}{1,728} = .68177 \text{ cubic foot.}$$

The weight of an equal volume of water $= .68177 \times 62.5 = 42.61063$ pounds. Now, in order to discharge this water, *all* of the water in the suction and delivery pipes had to be moved through a certain distance in feet equal to .68177, divided by the area of the pipes in square feet.

4 inches $= \frac{1}{3}$ of a foot. $(\frac{1}{3})^2 \times .7854 = \frac{.7854}{9} = .0872\frac{2}{3}$ sq. ft. $.68177 \div .0872\frac{2}{3} = 7.8125$ feet.

The weight of the water in the delivery-pipe is $(\frac{1}{3})^2 \times .7854 \times 100 \times 62.5 = 545.42$ pounds.

The weight of the water in the suction-pipe is $(\frac{1}{3})^2 \times .7854 \times 25 \times 62.5 = 136.35$ pounds.

$545.42 + 136.35 = 681.77$ pounds $=$ the total weight of water moved in one stroke. The distance that it is moved

in one stroke is 7.8125 feet. Hence, the number of foot-pounds necessary for one stroke is $681.77 \times 7.8125 = 5,326.33$ foot-pounds. Had this result been obtained by the rule given in Art. **2220,** the process would have been as follows: The weight of the water displaced by the piston in one stroke was found to be 42.61063 pounds. $42.61 \times 125 = 5,326.33$ pounds, which is exactly the same as the result obtained by the previous method, and is a great deal shorter.

EXAMPLE.—What must be the necessary horsepower of a double-acting steam-pump, if the vertical distance between the point of discharge and the point of suction is 96 feet? The diameter of the pump-cylinder is 8 inches; the stroke is 10 inches, and the number of strokes per minute is 120. Add $\frac{1}{3}$ for friction, etc.

SOLUTION.—Since the pump is double-acting, it raises a quantity of water equal to the volume displaced by the plunger at every stroke. The weight of the volume of water displaced in one stroke $(\frac{8}{12})^2 \times .7854 \times \frac{10}{12} \times 62.5 = 18.18$ lb., nearly.

$18.18 \times 96 \times 120 = 209,433.6$ foot-pounds per minute.

Since $\frac{1}{3}$ is to be added for friction, etc., the actual number of foot-pounds per minute is $209,433.6 + \frac{209,433.6}{3} = 279,244.8$.

One horsepower $= 33,000$ foot-pounds per minute; hence, $\frac{279,244.8}{33,000} = 8.462$ H. P., nearly. Ans.

DUTY OF A PUMP.

2222. *The* ***duty*** *of any pump or pumping-engine is the number of pounds of water raised one foot high for each 100 pounds of coal burned in the boiler.*

2223. The duty is calculated by multiplying the number of pounds of water discharged in one hour by 100, and by the total height in feet that the water is lifted, and dividing the product by the number of pounds of coal burned during the hour. Since the discharge is usually given in gallons, the following formula may be used, in which

G = number of gallons discharged per hour;

h = total vertical distance in feet between the level of the water in sump, or other source of supply, and the point of discharge;

[illegible]

$$[illegible]$$

[illegible]

$$[illegible]$$

[illegible] Ans.

2224. [illegible] the highest duty test on record, [illegible] of the triple-expansion type, [illegible] the best coal being [illegible] foot-pounds [illegible] of the coal. This is considered a remarkable result.

MINE-PUMPING MACHINERY.

2225. Cornish Pumping-Engines.—Until within [illegible] times, the so-called **Cornish pumping-engines** [illegible] used for removing the water from the mines. This engine was invented by Watt for use in the mines of Cornwall, and was the first [illegible] steam-engine made. An illustration of a Cornish pumping-engine is shown in Fig. 760. The cylinder *A* is single-acting; that is, the steam acts only on one side of the piston. Its diameter is, in this case, 70 inches, and its stroke is 10 feet. *B* is the piston-rod; it is connected to the walking-beam *C* by a link *R*. In Cornish [illegible]-engines, the steam is admitted, through the valve [illegible] top of the piston, and forces it down towards the

bottom of the cylinder. The weight of the pump-rods and other moving parts in the shaft, called the **pit-work,** is

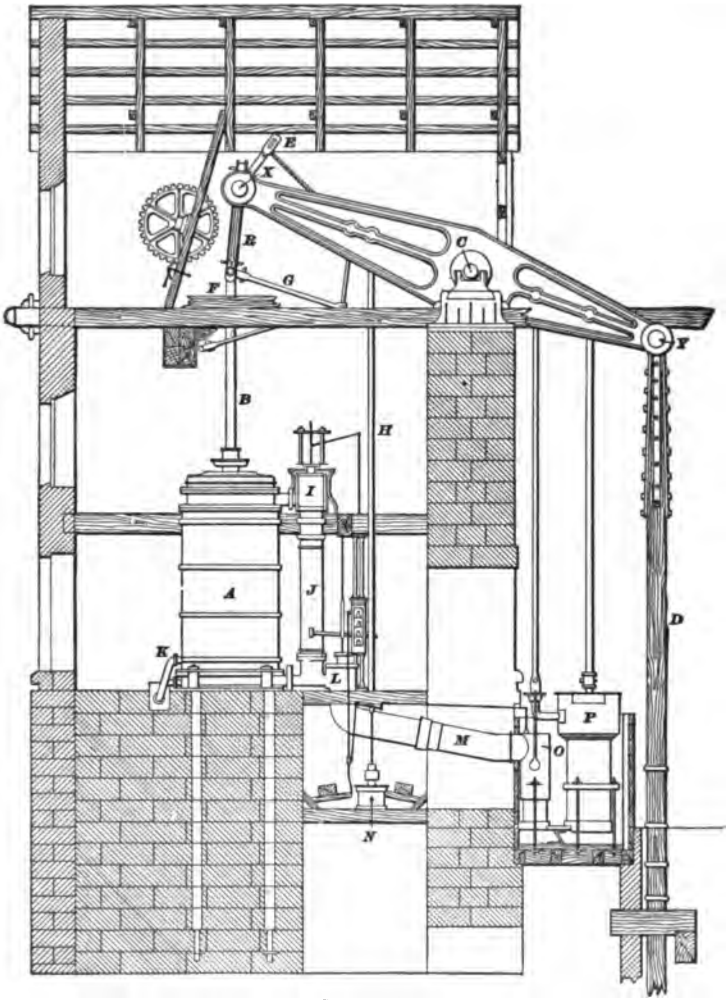


FIG. 760.

sufficient to raise the piston to the top of the cylinder when the steam on the upper side of the piston is put in communication with the lower side. The cylinder A is steam-jacketed; that is, the cylinder-walls are hollow, and filled

[illegible] is longer [illegible] to have the [illegible] steam-cylin- [illegible] is desired to [illegible] represents the length of the [illegible] $s \times \frac{CY}{XC}$, when XC and CY represent the lengths of the two arms of the beam as shown in the cut.

[illegible] Cornish Bull Engine.—In Fig. 761 are shown [illegible] Cornish Bull engine and pump. This style [illegible]gine is made by many firms, and differs but [illegible] regard to details. Here the walking-beam is

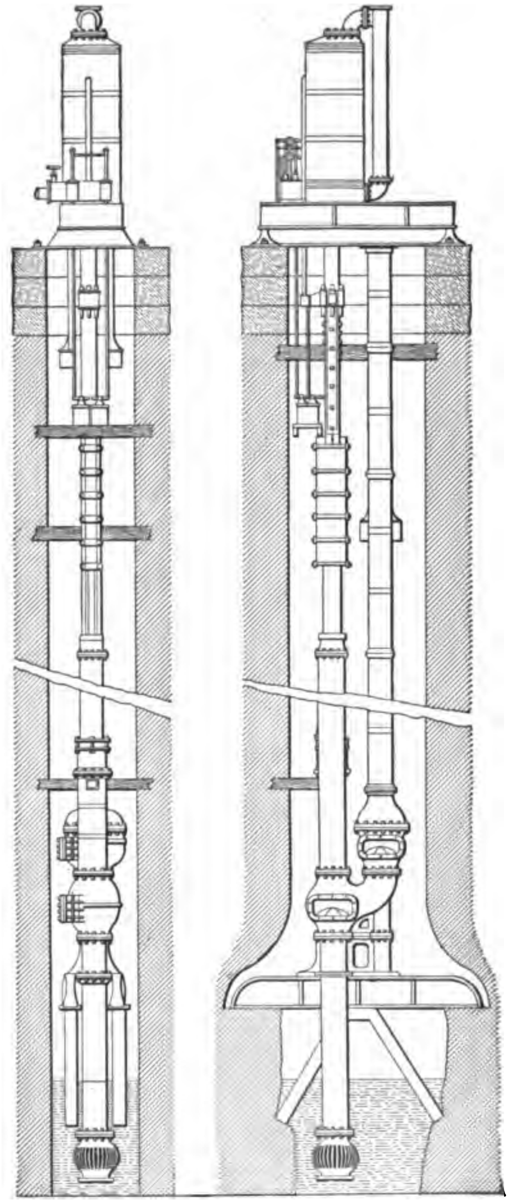


FIG. 761.

dispensed with, and the cylinder is placed directly over the shaft, the pit-work being attached to the piston itself. In this case also the cylinder is single-acting, the steam being admitted below the piston instead of above it, as in the engine described in Fig. 760. The condenser is usually omitted in this class of pumps, the steam exhausting directly into the atmosphere. The pump shown is for a single lift; for depths greater than about 350 feet, the lift is generally in two or more operations, which will be described later. In case the weight of the pit-work should be greater than necessary to force the water up the required height, the extra weight is counterbalanced in a manner to be described later.

The Bull pumping-engine possesses several advantages over the Cornish pump. The heavy walking-beam and its connections are dispensed with; this lessens the first cost; the friction is greatly reduced; the advantage of having a direct-acting engine is also obtained. The principal disadvantage is that, the pump being directly over the shaft, it takes up a great deal more room, where space is necessary, than the Cornish pump.

Cornish and Bull pumps both use steam expansively. They do not have fly-wheels to absorb the energy of the early part of the stroke and give it out again at the end, but utilize the heavy pit-work to accomplish the same purpose. The number of expansions ranges from four to ten; that is, the steam is cut off from $\frac{1}{4}$ to $\frac{1}{10}$ stroke. When using more than 6 expansions ($\frac{1}{6}$ cut-off), the strain produced on the machinery becomes very heavy, and the resulting wear and tear of the machinery more than makes up for the increased economy in the use of steam. Many engineers claim that four expansions are the most economical.

2227. In the following table, the sizes of a number of Bull engines and pumps in use in the Wyoming coal-fields are given. The number of gallons discharged, given in this table, is the actual quantity delivered.

ENGINES.

Diameter of Cylinder.	Length of Stroke.	No. of Strokes per Minute.	Diameter of Steam-Pipe.	Diameter of Exhaust-Pipe.
36 in.	9 ft.	15	6 in.	8 in.
50 in.	10 ft.	12	8 in.	10 in.
60 in.	10 ft.	10	9 in.	12 in.
70 in.	10 ft.	8	10 in.	14 in.

PUMPS.

Diameter of Plunger.	Stroke of Plunger.	Diameter of Suction-Pipe.	Diameter of Discharge-Pipe.	Gallons per Minute.	Height of Lift.
20 in.	9 ft.	20 in.	20 in.	2,203	84 ft.
20 in.	10 ft.	21 in.	21 in.	1,958	300 ft.
22 in.	10 ft.	23 in.	23 in.	1,975	600 ft., 2 lifts.
24 in.	10 ft.	25 in.	25 in.	1,880	833 ft., 2 lifts.

2228. In nearly every case where surface pumps are used to raise water from great depths, plunger (force) pumps are employed, the weight of the pit-work, which includes the weight of the plungers, being sufficient to overcome the weight of the water and the friction attending its motion.

2229. In Fig. 762 is shown a section of a lifting-pump for use in mines. The pump consists of a series of pipes connected together, of which the lower end only is shown in the cut. That part of the pipe included between the letters *A* and *B* forms the pump-cylinder, in which the piston *P* works. The part above the highest point of the piston travel is the delivery-pipe, and the part below the lowest

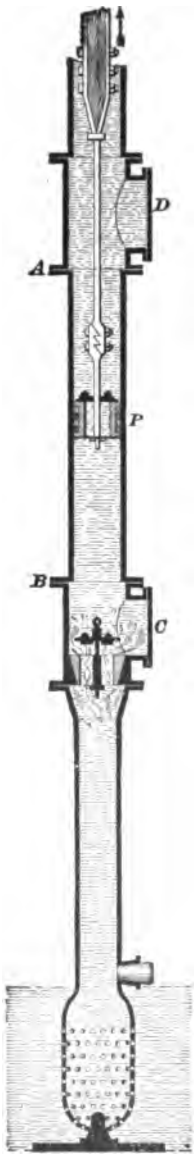


Fig. 762.

point of the piston travel is the suction-pipe. When speaking of these parts as applied to mine-pumps, the delivery-pipe is usually termed the **working barrel,** and the suction-pipe the **wind-bore.**

In all cases of mine-pumps, the lower end of the wind-bore is pear-shaped, and perforated with many small holes, to keep solid matter in the water from entering the pump and destroying the valves. In some cases, the pear-shaped end is covered with gauze for the same purpose. *C* is a plate covering in the pipe, which may be removed to allow the suction-valve to be repaired. *D* is another plate covering a similar opening, to allow the piston and piston-valves to be repaired. The piston-rod, or, rather, the piston-stem, is made of wrought iron, inserted with wood, and connected to the piston in the manner shown by the cut. The only limit to the height to which a pump of this kind can raise water is the strength of the piston-rod. The pipe continues straight upwards in the direction of the arrow.

The piston-rod is raised by means of an engine situated at the surface—either a Cornish engine, Bull engine, or an ordinary horizontal steam-engine—operating a walking-beam in a manner hereafter to be described.

2230. The lifting-pump shown in Fig. 755, where a separate pipe is used to convey the water from the pump-cylinder to the point of discharge, requires the pump-rod to be round, and to pass through a stuffing-box, as shown, in order to prevent

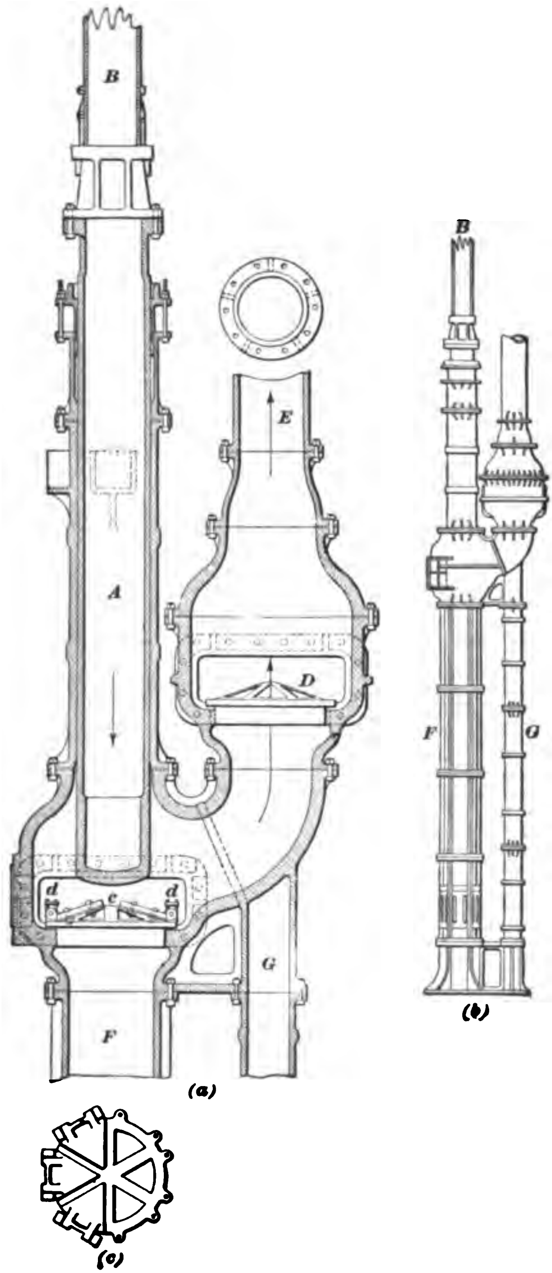


FIG. 763.

leakage. The pump shown in Fig. 762 may have a rod of any shape, and no stuffing-box is required.

2231. In Fig. 763 is shown a **plunger-pump** (force-pump) used in connection with the Bull engine shown in Fig. 761; (*b*) is an elevation of the pump, and (*a*) is a section drawn to a larger scale, showing the pump-cylinder and valves. As will be seen, the plunger *A* is hollow, the weight of the heavy rod *B* and connections being sufficient to raise the water to the required height. The method of attaching the rod to the plunger is fully shown by the cut. Suppose the plunger to be on the down (indoor) stroke; the valve *c* is, of course, closed; the water filling the pump-cylinder is forced through the valve *D*, which it opens, and up the delivery-pipe *E*. When the plunger reaches the end of its stroke and begins its return, the weight of the water forces the valve *D* to its seat, retaining the water above it in the discharge-pipe *E*. As the plunger moves upwards, it leaves a partial vacuum behind it, causing the water to rush up the suction-pipe *F*, lift the valve *c*, and fill the pump-cylinder. The plunger makes another downward stroke, and the above process is repeated. *G* is a standard attached to the delivery-pipe, the lower end resting on a foundation. This is necessary, since the great weight of the water in the discharge-pipe and the weight of the pipe itself would break it off at the bend, unless supported in some such manner; otherwise the thickness of the metal around the bend would necessarily be enormous.

A top view of the valves is shown at (*c*). They consist of six triangular valves arranged in a circle, with their apexes pointing towards the center. These six valves turn upwards on hinges, and are prevented from going too far by the projection *d*; see (*a*). Three of the valves have been removed so as to show the amount of valve-opening which they give. When the valves are open, they form an angle of about 45° with their position when closed.

2232. Advantages and Disadvantages of Lift-Pumps.—It is easier to specify the objections to lift-pumps

than to state their advantages over the plunger-pumps. The pump-rod, being necessarily inside of the delivery-pipe, reduces the effective area of pipe, and increases the friction of the water to some extent, owing to the added surface rubbed against. The rods are concealed, and can not be inspected without removing the entire rod. Not only do the bolts and rods sometimes break, thus rendering their recovery difficult, but the bolts will wear against the stocks, causing loss of power by friction and destroying the pipes.

Lift-pumps are not so liable to sudden injurious strains as the plunger-pumps. They are better adapted for sinking purposes than the plunger-pumps, the impurities in the water being less harmful than in the case of plunger-pumps.

The plunger type of pumps is superior to the lift-pump in nearly every respect for very high lifts, with the accompanying heavy pressure, or when dirty water is being raised. When pumping against a heavy pressure, it is impossible to keep the piston of lift-pumps tight, and prevent the water from leaking. The piston and cylinder of the lift-pump must in every case be a perfect fit, and be truly cylindrical. With plunger-pumps, on the contrary, the rod passes through a stuffing-box, and the plunger may or may not fit the cylinder. When pumping dirty water, the grit comes in contact with the surface that the piston of a lift-pump is constantly traveling over, and destroys both the cylinder and piston very rapidly; whereas, the plunger has to be kept tight at only one permanent place, and the dirt cannot very well get at the surface of the packing on which the plunger or plunger-rod rubs. Every part of a plunger-pump can be readily examined and repaired without taking down the whole apparatus.

PUMP DETAILS.

VALVES.

2233. A section of a pump clack-valve is shown in Fig. 764. *A* and *B* are the clacks, lined with leather on the bottom, to make a tighter fit on the seat, and thus do away with the necessity of grinding the valve when fitting. *C* is

a small casting for the clacks to strike against, so as to prevent them from opening too far, and E is the pin or axle on which they turn. D is a cylindrical casing having a flange around the outside near the middle. The upper part of this casing forms the valve-seat. These valves are of the

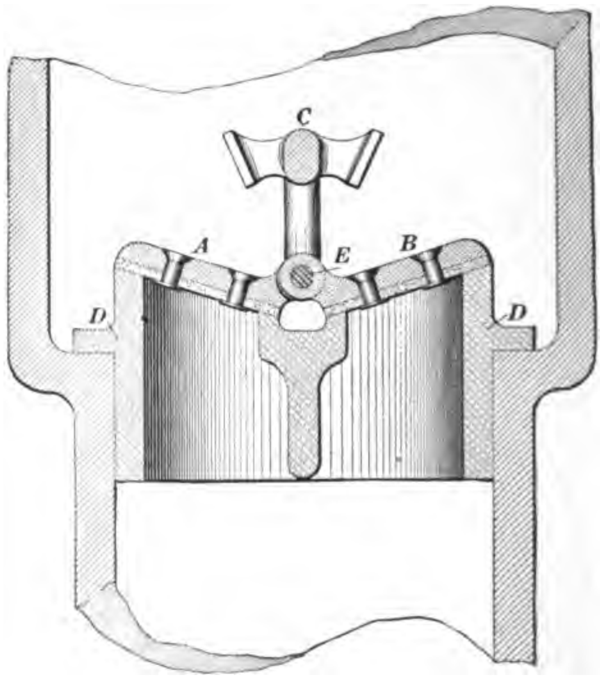


FIG. 764.

type known as the **butterfly valve,** and are used more than any other form for pumps at collieries, principally because of their cheapness, simplicity of construction, and the fact that they can be set up, repaired, or replaced by any one who is handy with tools.

2234. Fig. 765 shows a section of what is termed a **single-beat valve.** A is the valve; B is a stem which forms a part of the back of the valve and acts as a guide in the bearing D. C, C, C, C are rubber rings, kept in position between the flange of the fixed bearing D and the

back of the valve A by means of the stem, and separated by the washers E, E, E. When the water raises the valve, the rings are compressed, and the shock which would be produced by the valve striking the flange is done away with, and with it the liability of breaking the valve. The rings likewise assist in closing the valve. This is called a single-beat valve,

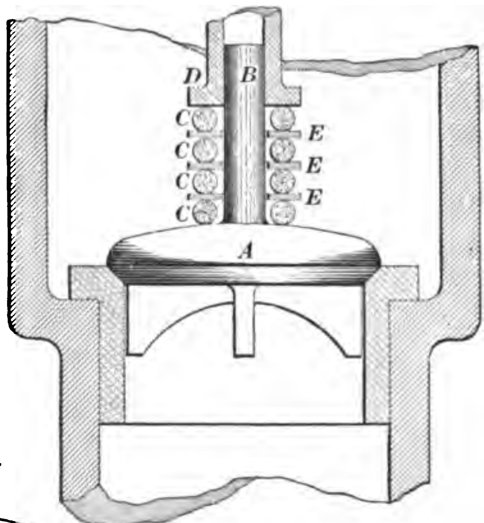


FIG. 765.

because there is but one opening. These valves are used for lifts up to 500 feet.

2235. For lifts up to 300 feet, India-rubber disk valves give good satisfaction. Fig. 766 shows one of ordinary construction. An India-rubber disk A is fixed over the center of the grid B. When the water rushes through the holes, the rubber disk is lifted at its ends until it strikes the curved piece C, which

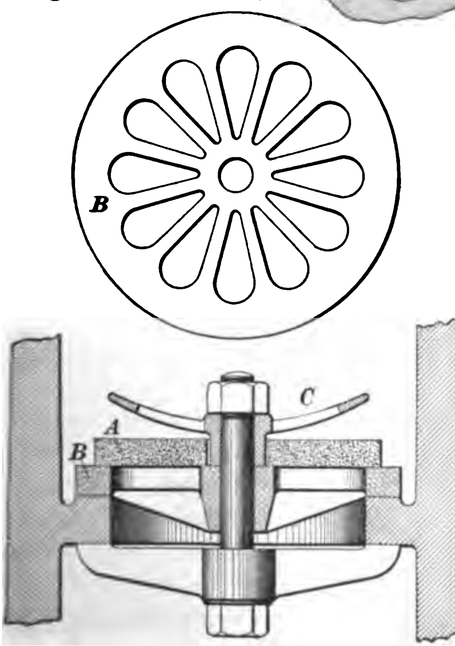


FIG. 766.

is placed there to keep the valve from opening too far. The grid, or seat, *B* is filled with holes, through which the water passes. This valve works well, but is not satisfactory on account of the necessity of constantly renewing it. The valve can not turn, and, therefore, rises and falls back into the same position every time. In consequence of this, the heavy water causes those portions of the rubber disks which cover the holes in the seat to be pressed inwards, and the valves wear out very fast. To obviate this difficulty, the holes in the grid are slanted, as shown in Fig. 767, and a small brass collar is fixed to the center of the disk. The water, rushing in at an angle, rotates the valve slightly each time, thus presenting a new surface to the holes in the seat, and reducing the wear to a minimum. In a later construction of this valve, the grid passages are vertical, as in Fig. 766, but the disk itself has inclined teeth cut in the circumference. This answers the same purpose as the method shown in Fig. 767, and is superior to it, since the direction of the water is not changed by inclined openings.

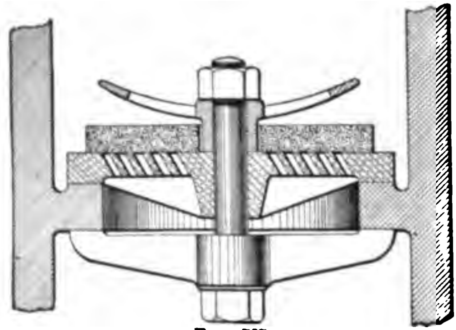


FIG. 767.

2236. A section of a **Cornish double-beat** valve is shown in Fig. 768. This valve is deservedly a favorite, and is used when high pressures are required. Besides being used for a water-valve, it may be used for steam or air. These valves have been applied to pumps working against a head of 700 feet with entirely satisfactory results. They are called double-beat valves because they have two seats and two openings for discharge. *A* is the casing which slides on the vertical stem *B*; when down, it rests on the valve-seats at *C* and *D*. When the pressure below becomes

greater than that above, it raises the casing, and the water is discharged through the circular openings at *C* and *D*. The rib around the outside of the casing is for the purpose of strengthening it. The valve-seats are conical. The

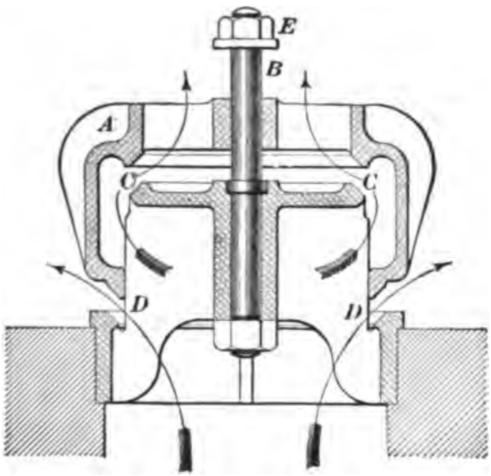


FIG. 768.

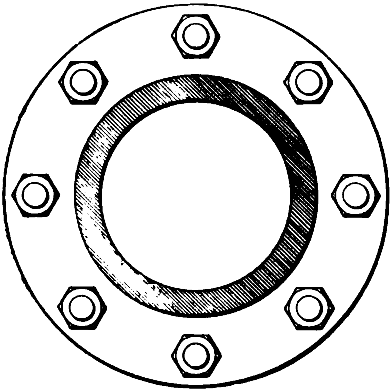
figure shows that one opening discharges the water outside of the valve, and the other through the inside. In some cases the valve-seats are flat instead of conical, and have a strip of rubber extending around the entire seat.

PIPES.

2237. The pipes used to convey the water from the mine to the surface are generally made in sections of about ten feet in length, with flanges on each end to bolt them together. The usual practice is to make them of cast iron; when the water is not injurious, however, they are sometimes made of wrought iron, on account of the great reduction in weight; wrought iron being so much stronger than cast iron, the thickness of the pipe may be a great deal less.

A number of different forms of joints are used, one of the best being shown in Fig. 769. The projection *B* (sometimes called a *spigot*) is made just strong enough to prevent its being broken when connecting up the pipes; its

purpose is to keep the pipes in line. *C* is a ring of lead, or wrought iron, from $\frac{1}{8}$ to $\frac{1}{4}$ inch thick; its purpose is to make a tight joint, and it is wrapped with flannel, or common woolen cloth, soaked in tar. The lead ring is preferred on account of the wrought-iron one having a decided tendency to corrode. When wrought-iron rings are used, the pipes must be faced, but this is not necessary when lead is employed, owing to its softness. In all first-class work the pipe-flanges are faced. The bolts are distributed around the flange, as shown in the plan.



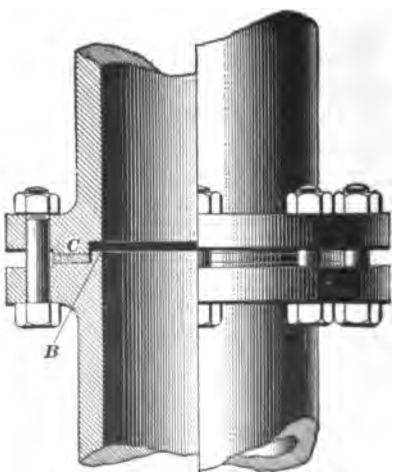


FIG. 769.

2238. A somewhat similar joint is shown in

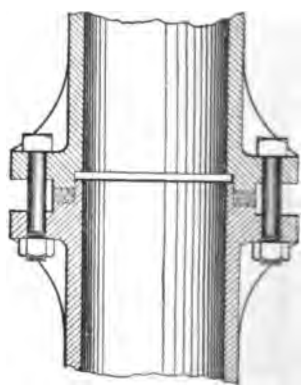


FIG. 770.

Fig. 770. Here the flange is strengthened by heavy ribs, to prevent its being broken when tightening the nuts.

2239. A very good joint, which will withstand pressures up to 1,000 pounds per square inch, is shown in

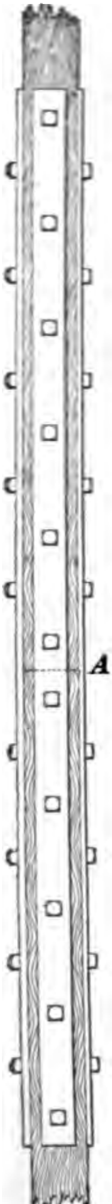


Fig. 771. It consists of two ordinary flanges, faced straight across, having a triangular groove cut in each. A gutta-percha cord is made into a ring by cutting its ends beveling, and making the cord of just such a length as will equal the circumference of the **V** groove. The cord is then laid in the groove with the two ends matching, and when the nuts are screwed down, the cord spreads, filling the entire groove as shown. The greater the pressure in the pipe, the greater the stress on the flat surface of the triangular ring; consequently, the greater the compression of the gutta-percha, the better the joint.

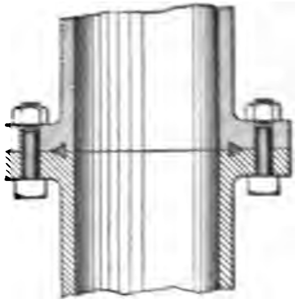


FIG. 771.

ROD-JOINTS.

2240. A method of connecting the different sections of the pump-rod (also called *spear-rod*) is shown in Fig. 772. Here the two ends of the rod are squared, and placed butt to butt at *A*. Four wrought-iron plates are then bolted on, the bolts passing through the rod. Some colliery engineers object to four plates, claiming that the extra bolts reduce the strength of the rod too much; hence they use two plates. Four plates stiffen the rod a great deal more than two, and, since the rods are usually made a great deal larger than absolute strength requires, it is better to have four plates than two. These plates, called **strapping-plates,** are usually made thick in the middle, where the joint comes, and then tapering in both directions to half that thickness at the ends. Many engineers make them of equal thickness the whole length, in order to save the extra cost of forging.

FIG. 772.

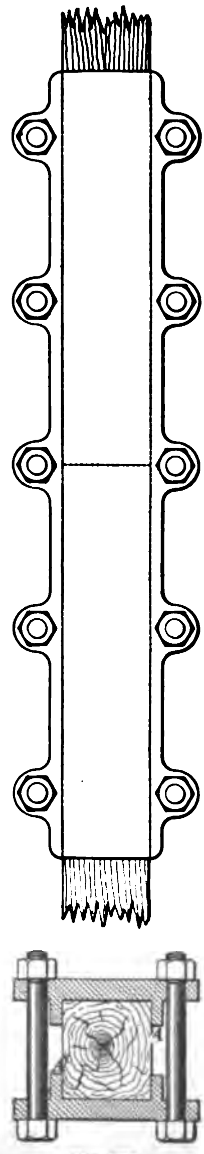


FIG. 773.

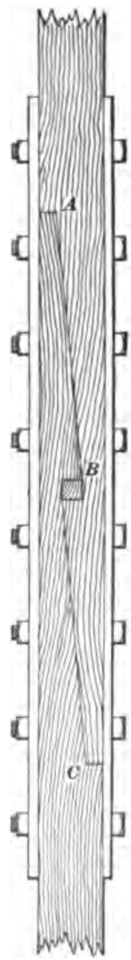


FIG. 774.

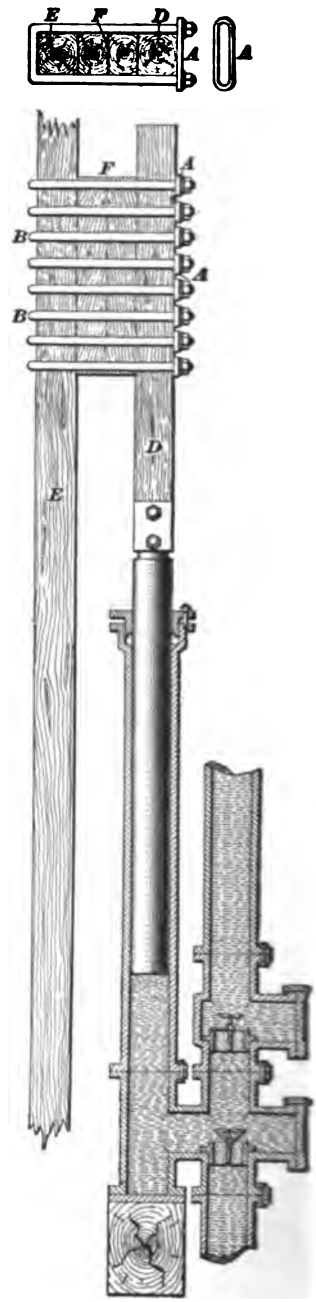


FIG. 775.

2241. Fig. 773 shows two views of a joint in which cast-iron strapping-plates are used. In this case, the bolts do not pass through the rod, but to one side. Two plates are used, which have rectangular-shaped lugs *A*, on the bottom, between which the wooden part of the rod fits exactly. The two parts of the rod are held together by the friction between the rods and the plates. This is an excellent joint, and is to be commended, when properly made.

2242. In Fig. 774 is shown another excellent joint, which must be made with great care. The two ends of the pieces forming the joint are cut like *A* and *C*. They are placed together, and the two strapping-plates put on similarly to the method shown in Fig. 772. Then a square pin *B* is driven in, and in the best construction two other plates are bolted to the other two sides. This is a costly joint, on account of the great care necessary to make the two pieces fit. It is a good plan, however, to use it when practicable. All pieces forming the rod should be of equal length, in order that one piece may be readily taken out and replaced by a duplicate, when repairs are necessary. A fair length to allow would be thirty feet. They should be longer, rather than shorter than this, in order to reduce the number of joints, but it would be well not to exceed forty-five feet. In all cases, the joints should be so made that there will be no "lost motion"; that is, that there shall not be any space between the two ends joined together, so that they will be liable to wear and have a little end-play when the direction of the stroke is reversed. All such lost motion shortens the stroke of the engine, and lessens the discharge, besides increasing the wear and tear.

2243. When several plungers are operated by one rod, as is usually the case with deep shafts, they are connected to the rod by means of an **off-set**, see Fig. 775. The cut shows three views of the most common method adopted for uniting the plunger-pole and the main pump-rod. *D* is the plunger-pole; *E* the main pump-rod; *F* the off-set; *B*, *B* are staples made of round iron bars, on which a screw-thread

is cut at each end; *A*, *A* are the glands or cross-bars, shown in the plan, against which the nuts are tightened.

CATCHES.

2244. In order to prevent the pump-rods from falling down the shaft, in case of the valve-gear refusing to work, and thus allowing the piston to blow through the cylinder, a catch is located at the top of the shaft. Fig. 776 shows

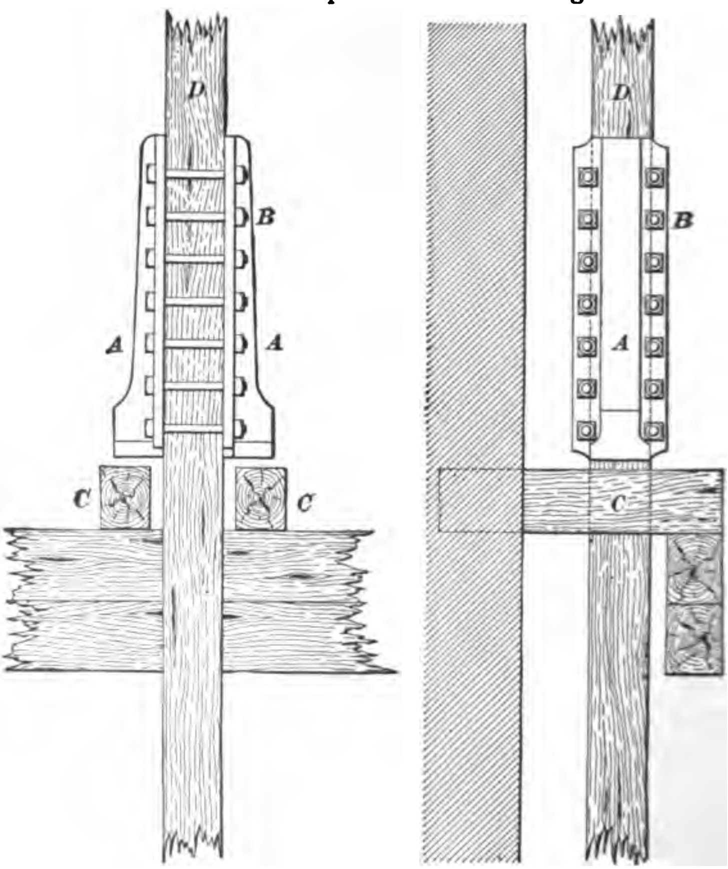


FIG. 776.

the arrangement of one of these catches. It consists of two cast-iron pieces *A*, *A*, attached to the pump-rod *D* by

means of bolts. These bolts do not pass through the rod, but are situated on the sides, very close to it, so as not to weaken the rod. *C*, *C* are two banging-pieces, one end of which is carried to the sides of the shaft, the other end being secured to two beams which are stretched across the shaft, and between which the rod moves. The catch and banging-pieces are so located that the piston can not touch the cylinder-head in any case.

Another method is to secure two wooden pieces on each side of the rod by means of bands having screw-threads cut on the ends, in much the same manner that the off-set was arranged in Fig. 775. When the shaft is very deep, and there are several plungers operated by one rod, it is usual to have a catch near each plunger.

GUIDING THE RODS.

2245. The usual manner of guiding the rods is illustrated in Fig. 777. Two beams *A*, *A* are placed across the

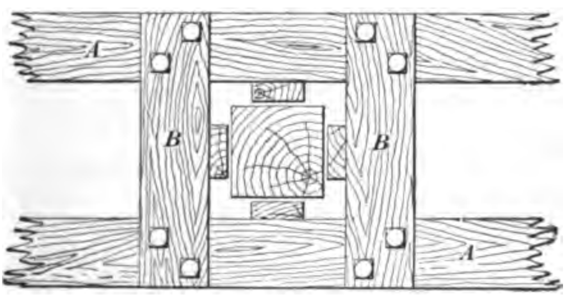
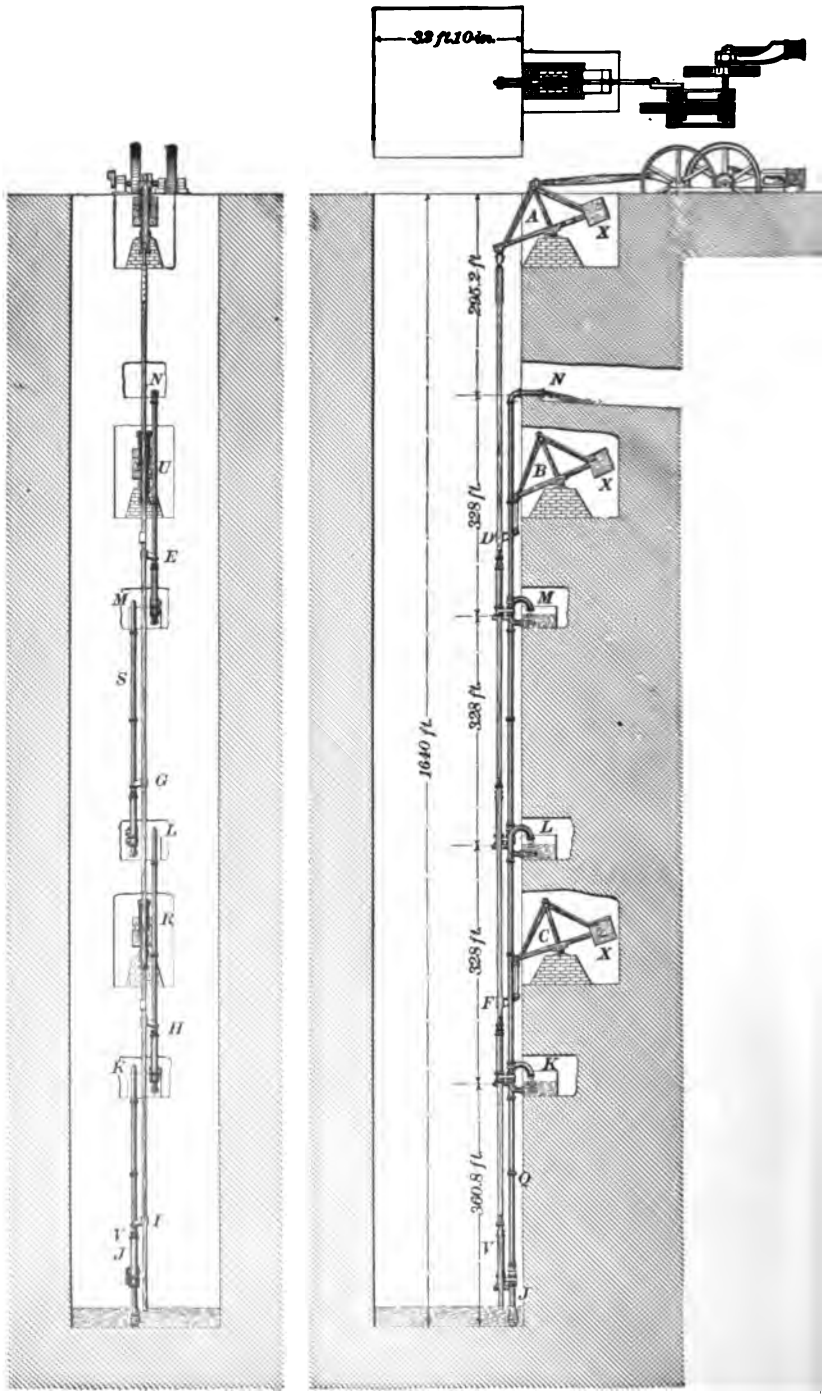


FIG. 777.

shaft, and two crosspieces *B*, *B* are attached to them. On each of these four pieces is a rubbing-block, the rod sliding loosely between them.

GENERAL ARRANGEMENT.

2246. The entire arrangement of shaft, pump-rods, engines, counterweights, etc., is shown in Fig. 778. Instead of a Cornish or Bull engine, as has been heretofore described, an ordinary horizontal engine is used.



33 ft.10 in.
N
U
E
M
S
G
L
R
H
K
I
V
J
A
X
295.2 ft.
N
B
X
328 ft.
D
M
328 ft.
1640 ft.
L
C
X
328 ft.
F
K
360.8 ft.
Q
V
J

The type of engine employed in this case is a **Corliss-geared engine.** Fig. 779 shows in greater detail an engine of different make, but the same in principle as the one shown in Fig. 778, and which is used for the same purpose. In an arrangement of this kind, it is necessary that the pump-rod should move very slowly while the steam economy is increased by higher speeds. Hence, in Fig. 779, the crank-shaft has keyed to it a stepped pinion, which meshes into a very large stepped gear-wheel. A second crank is keyed to the shaft of the large gear-wheel, and to it is attached one end of a long wooden connecting-rod *T*, whose other end is attached to a bell-crank in a manner shown more clearly in Fig. 778. The second crank thus communicates its motion to the bell crank *A*, Fig. 778, which in turn operates the pump-rod in the shaft.

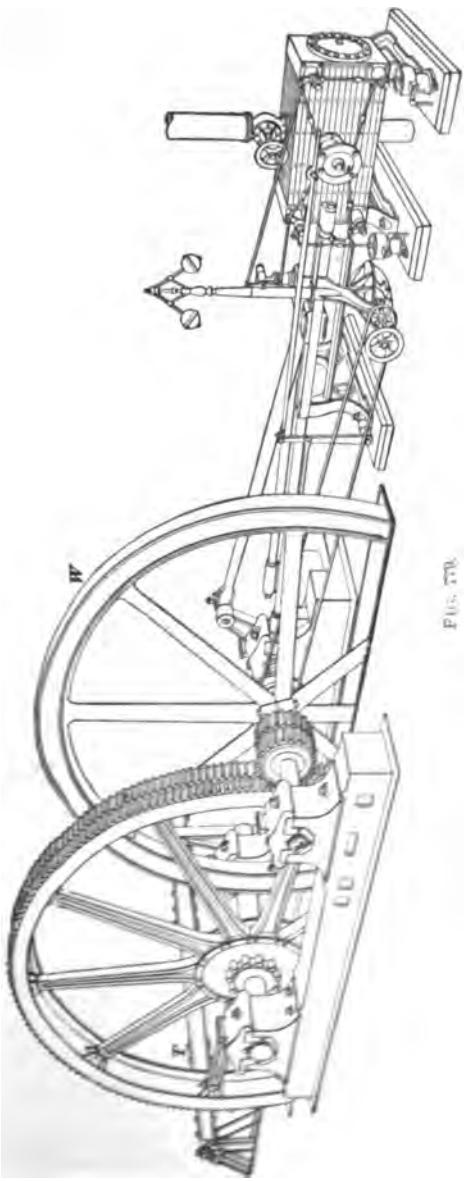


FIG. 779.

On account of the great length of the rod (over 1,600 feet), its weight added to the weight of the plungers is considerably more than the weight of the water-column; hence, to save the extra power which would be required to be used in raising this extra weight, it is counterbalanced. A counterbalance-weight *X* is placed on one end of the bell-crank *A*; two other bell-cranks, *B* and *C*, are located down the shaft, one end carrying the counterweight *X* and the other end being connected to the pump-rod by means of a link and the cast-iron off-sets *D* and *F*.

The shaft itself is square, one side measuring 32 ft. 10 in. The water is raised by four lifts, the first, to *K*, being 360.8 ft., and the other three 328 ft. each. In this particular instance, the water is discharged into a tunnel *N*, about 300 feet below the surface. The pump-rod goes straight down the shaft, and the discharge-pipes are placed alternately on each side of it. *J* is a suction-pipe; *I* is a bracket, one end of which is attached to the pump-rod and the other end to the pump-plunger *V*. On the down stroke, the water is forced out of the pump-cylinders and up the pipes *Q*, *R*, *S*, and *U*, discharging at *K*, *L*, *M*, and *N*. The discharge-pipe is 8 inches in diameter.

This pumping arrangement possesses several advantages over the Cornish or Bull pumping-engines. The fly-wheel permits a more even distribution of the power. The length of the stroke is always the same, and there is no danger of damage caused by the piston being blown through the cylinder-head, should the valve-gear refuse to work.

The crank, instead of being made as shown, may be made in the form of a circular disk, and have several pins on it at varying distances from the center, so that the stroke of the engine may be lengthened or shortened, if desired. This, however, is not recommended. The engine can also run at a great deal higher speed, while the pump-rods move no faster than the Cornish type. The gears increase the engine friction to some extent, but the loss from this source is probably no more than in the case of the walking-beam engine.

BALANCING THE PUMP-RODS.

2247. It has been stated that the water is forced upwards by the weight of the descending pit-work. The weight of the pit-work must then, of course, be greater than the weight of the ascending column of water, and the velocity of the descending pit-work will depend directly on the difference between its weight and the weight of the water-column. There is, however, a practical limit which the speed of the pit-work may not exceed; viz., about 200 feet per minute, or less. One reason for this limit is the liability of the piston to pound the cylinder-head, if moving too fast; and another is that the velocity of the water in the pipe should be not more than 200 to 250 ft. per minute. If, then, the difference between the weight of the pit-work and of the water-column be too large for the required velocity, a balance-bob must be resorted to, as shown in Fig. 778. The pump-rod, in descending, has not only to raise the water-column, but also to lift the weight at the end of the bell-crank. The speed of the descending pit-work can thus be exactly regulated by the weight of the balance.

2248. As an example, suppose the weight of the pit-work is 20 tons, the weight of the water-column raised is 16 tons, and the frictional resistances, say, 3 tons. First find the velocity of the pit-work on the down stroke, and see if the pump-rod needs to be balanced. The total force is 20 tons, and the total resistance is $16 + 3 = 19$ tons, leaving a net force of 1 ton to accelerate the moving mass. The weight to be accelerated is $20 + 16 = 36$ tons; the friction, of course, not requiring acceleration. The formula which expresses the relation between the force, acceleration, and weight, is

$$f = \frac{g\,F}{W}, \qquad \textbf{(188.)}$$

where F is the force; W, the weight; f, the acceleration in feet per second, and g, the acceleration due to gravity, which is usually taken as 32.16 ft. per sec. in a second.

Substituting the values of F, W, and g, in formula **188**,

$$f = \frac{32.16 \times 1}{36} = .89\tfrac{1}{3} \text{ ft. per sec. in a second.}$$

That is, *the velocity increases regularly at the rate of* $.89\frac{1}{3}$ *ft. per sec.*

2249. Assuming the stroke of the engine to be 10 ft., the time of one stroke, when the piston has the acceleration given above, is found by the following formula:

$$t = \sqrt{\frac{2\,s}{f}}, \qquad \textbf{(189.)}$$

in which t is the time in seconds, and s is the space passed over in feet. Substituting, $t = \sqrt{\frac{2 \times 10}{.89\frac{1}{3}}} = 4.732$ seconds.

Ten feet in 4.732 seconds is at the rate of $\frac{10}{4.732} \times 60 = 127$ ft. per min., nearly, which is well within the required velocity, and, therefore, no balance is needed. In fact, the pump-rod might advantageously be weighted a little, and its speed thereby increased.

Suppose, however, that instead of 20 tons the pit-work had weighed 24 tons, the other conditions remaining the same. The net force free to produce acceleration would then be $24 - 19 = 5$ tons, and the weight to be accelerated would be $24 + 16 = 40$ tons. Using formula **188**,

$$f = \frac{g\,F}{W} = \frac{32.16 \times 5}{40} = 4.02 \text{ ft. per sec.}$$

Substituting this value of f in formula **189**,

$$t = \sqrt{\frac{2\,s}{f}} = \sqrt{\frac{2 \times 10}{4.02}} = 2.23 \text{ sec., nearly.}$$

Since the stroke of 10 feet is made in 2.23 seconds, the average velocity per minute is $\frac{10}{2.23} \times 60 = 269$ ft. per minute. As this speed is rather too high, it should be reduced by means of a counterweight. Suppose that a counterweight of two tons be tried. The weight of the pit-work is, as before, 24 tons; the weight which it puts in motion is 16 tons (weight of water) plus 2 (counterweight) = 18 tons. $24 - 18 = 6$ tons = force available to move the water, coun-

terweight, and to overcome the frictional resistances. Since the total weights have been increased from $16 + 20 = 36$ tons, originally, to $24 + 18 = 42$ tons, the frictional resistances have also been increased. Assuming them to be $3\frac{1}{2}$ tons now, the effective force left to produce acceleration is $6 - 3.5 = 2.5$ tons $= F$. Substituting in formula **188**,

$$f = \frac{32.16 \times 2.5}{42} = 1.9143 \text{ ft. per sec.}$$

Substituting this value of f in formula **189**,

$$t = \sqrt{\frac{2 \times 10}{1.9143}} = 3.2323 \text{ sec.}$$

Consequently, the speed in feet per minute is

$$\frac{10}{3.2323} \times 60 = 186 \text{ ft. per min., nearly.}$$

This is a fair speed, but should a higher rate be required, all that will be necessary will be to reduce the counterweight.

UNDERGROUND MINE-PUMPS.

2250. Underground direct-acting mine-pumps may be **simple** or **compound,** and either may be of the **single** or **duplex** type. They may be run by steam or compressed air, and the simple pumps (single or duplex) may also be run by water or electricity. There are many different makes of these pumps, which, like the steam-engine, differ more or less in their details, the principle governing each type being the same in all. In the following pages a description of one pump of each type will be given.

2251. In mine-pumps, plungers are almost invariably used instead of pistons. A **simple Worthington single pump** was shown in Fig. 758. By **single pump** is meant a pump which has but one pump-cylinder in contradistinction to the **duplex,** which has two, and the **triplex,** which has three, pump-cylinders. The words **simple** and **compound** refer to the steam-cylinder. Hence, a pump may be a **simple single** or a **simple duplex,** a **compound single** or a **compound duplex,** etc.

2252. The pump shown in Fig. 758 is, as mentioned before, a **simple single steam-pump.** When the water pumped is gritty and brings extraordinary wear upon the plunger and bushing that it slides in, which is attached to the partition *F*, a stuffing-box is placed at *F*.

The manner of attaching the stuffing-box is shown in Fig. 780. In this case the valve arrangement (not shown) is altered somewhat. A pump whose plunger is packed in this

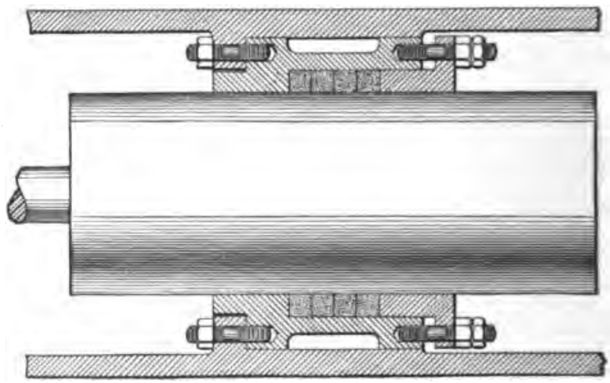


FIG. 780.

manner is called an **inside-packed pump.** Consequently, the pump shown in Fig. 758 would be called a **simple inside-packed single pump.** The great disadvantage in the use of this pump is that the water must be drained from the cylinder and the cylinder-head removed in order to repair the packing. In order to remove this difficulty, the so-called **outside-packed plunger-pumps** are used.

Fig. 781 shows a **simple outside-packed single mine-pump.** Two plungers *F* and *F'* are connected by the yokes *H* and rods *I*, on each side, so that both plungers move at the same time. The plunger *F* is attached directly to the piston-rod *P*. Suppose the steam-piston in *D* to be moving in the direction indicated by the arrow; the plunger *F* is then forcing water into the chamber *G*, and up the delivery-pipe *A*. The discharge-valve in the chamber *G'* is closed, and the plunger *F'*, being forced outwards by the yokes *H*

and rods I, leaves a vacuum behind it, which is filled by water from the suction-pipe. On the return stroke, the above operations are reversed, F' doing the forcing and F the suction. It should be understood that the cylinders in which F and F' work are separated by a partition at N, in somewhat the same manner as the two halves of the cylinder

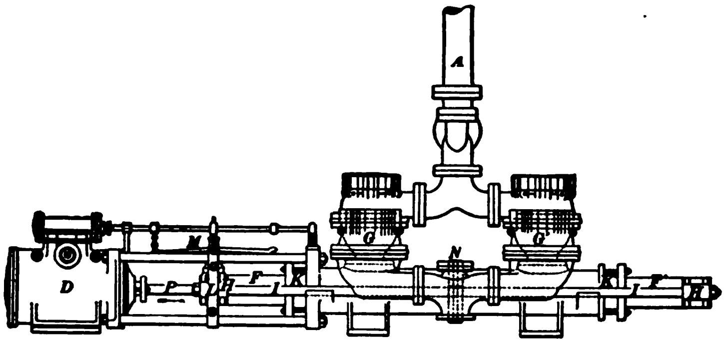


FIG. 781.

in Fig. 758. A detailed description of this arrangement applied to a pump of different manufacture will be described further on.

Two stuffing-boxes, K and K', are used to pack the plungers. As will be seen, they are outside of the cylinders, and the bushing can be easily removed, the packing repaired, and the bushing replaced without disturbing the cylinder-head itself in the slightest. The steam-valve is operated in this case by means of the lever M, carried to and fro by the upright-piece L, which is attached to the piston-rod P.

For most purposes, the outside-packed mine-pump is superior to the inside-packed type, but takes up more room.

2253. Fig. 782 shows a **Worthington simple outside-packed duplex mine-pump.** The plunger A has nearly completed its stroke in the direction indicated by the arrow, while the plunger B has completed the same portion of its stroke in the opposite direction. The steam-valve in the chamber D is operated by means of the crank F, acting through the long bearing G, and actuating the crank H, attached to the valve-stem by a link, as shown. The valve

in the chamber *E* is actuated in a similar manner by means of the crank *I*. These cranks are so set that the plungers *A* and *B* are always moving in opposite directions. This arrangement, in combination with the air-chamber *L*, produces a nearly uniform discharge. Both pump-cylinders dis-

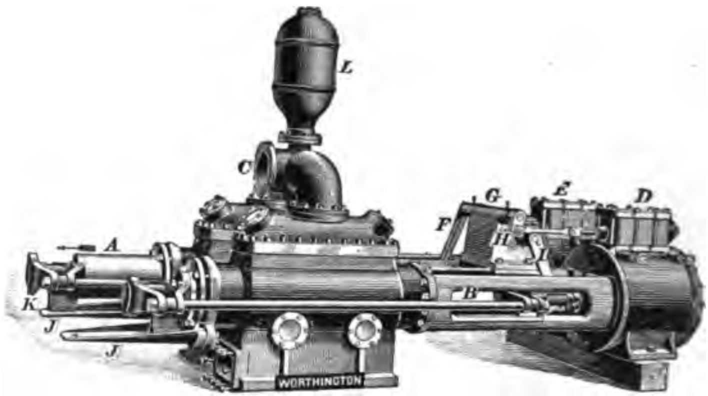


FIG. 782.

charge into the same delivery-pipe *C*. *K* is a *shoe*, one being attached to both ends of both plungers, and moves on the slide *J* at the left, and on the cross-head slide at the right. They prevent the ends of the plungers from falling downwards out of line when near the end of the stroke. The shoes are adjustable for wear. The ends of the plungers are connected by means of yokes and rods in a manner similar to the pump last described. As will be seen, it is outside-packed.

The chief disadvantage of this valve-driving arrangement is that one pump can not be disconnected from the other when the work would require only one pump to be in use. In order that one pump may run, the other must also be in motion.

2254. In Fig. 783 is shown a perspective view of a **Jeanesville compound outside-packed duplex mine-pump.** This is a very powerful pump, the one illustrated having the following dimensions:

Diameter of high-pressure cylinder......25 inches.
Diameter of low-pressure cylinder ......42 inches.
Diameter of pump-plungers............14 inches.
Stroke of plungers and pistons..........48 inches.

Its rated capacity is 2,000 gallons of water per minute against a head of 425 feet. In compound pumps, the steam is carried full stroke in both cylinders, the expansion being

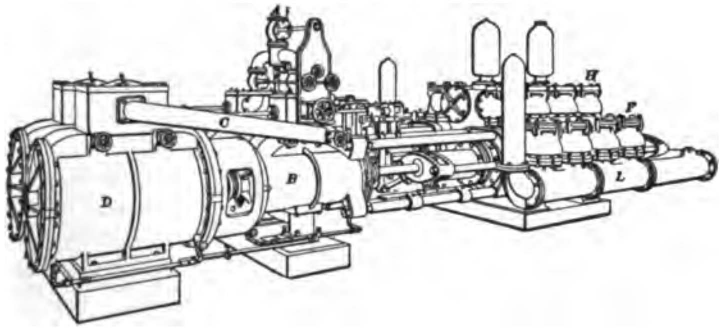


FIG. 783.

obtained through the difference of cylinder volumes. Since the stroke is the same in both cylinders in the pump shown in the figure, the volumes will be to each other as the squares of the diameters, or

volume of low-pressure cylinder : volume of high-pressure cylinder :: $42^2 : 25^2$.

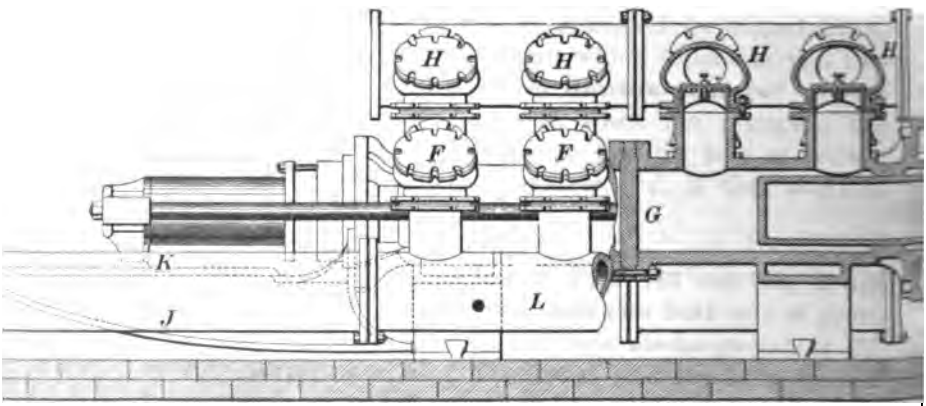
$$42^2 = 1,764\ ;\ 25^2 = 625;\ \frac{1,764}{625} = 2.82, \text{ nearly.}$$

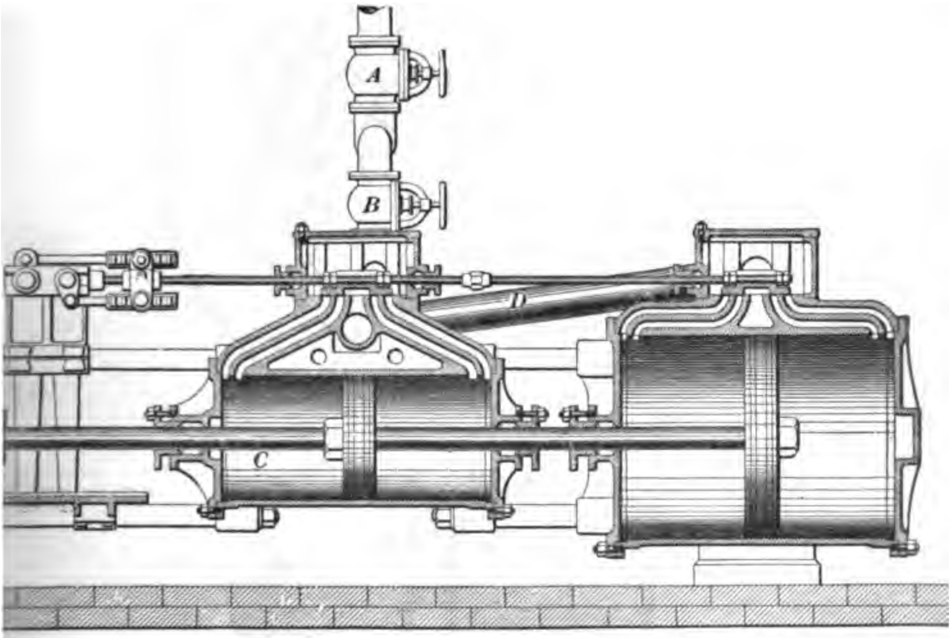
Hence, the volume of the low-pressure cylinder is, in this instance, 2.82 times that of the high-pressure cylinder, and the steam expands 2.82 times.

As this is a duplex pump, there are two high-pressure and two low-pressure cylinders. *A* is the throttle-valve; *B* the high-pressure cylinder of one pump; *C* the steam-pipe which connects one high with one low pressure cylinder, and *D* the low-pressure cylinder. The other pump is exactly similar. The throttle-valve *A* admits steam to both high-pressure cylinders.

2255. In order to show more clearly the working of the various parts of this pump, a sectional view is shown in Fig. 784. Here, *A* is the main throttle-valve; *B* is an auxiliary throttle-valve leading from the main valve to one of the high-pressure cylinders, a similar one being placed on the other side of the main valve connecting with the other high-pressure cylinder. The object of these auxiliary valves is to allow more or less steam to be admitted to one side in case it should appear to be doing less or more work than the other, the pump working better when both sides are doing the same amount of work. *C* is the piston-rod, to which are connected both pistons and the plunger *E*. The figure shows that the plungers are hollow. The form of the shoe *K*, which supports the ends of the plungers, can be clearly seen. The shape of the slide *J* on the back end, upon which the shoe moves, is indicated by dotted lines. *G* is the partition or diaphragm which separates the two plunger-cylinders. All so-called **double-plunger** pumps require this diaphragm, so that when the plungers are moving towards it, the water can find no way of escape except through the delivery-valves. *L* is the suction-pipe.

2256. Referring now to both Figs. 783 and 784, it will be noticed that there are eight valves for both sets of plungers, four suction-valves *F*, and four discharge-valves *H*, making 16 valves in all. The usual practice is to have a large number of small valves, from 50 to 100, for a pump of this size, instead of a small number of large valves. The mine water in the anthracite coal-fields attacks not only iron, but brass and phosphor-bronze as well, making the life of a valve-seating a limited one at best. This fact makes it imperative that pump-valves for mines be simple, strong, easy of examination, and quick of replacement. It is certainly easier to take care of 8 or 16 large valves than 50 to 100 small ones. Then, too, the parts of a large valve are heavier, and are less liable to be twisted or broken, owing to rough handling.


H
H
H
H
F
F
G
K
L
J


A
B
C
D

2257. A section through two of the discharge-valves is shown in Fig. 784. In order to more clearly show the working of these valves, an enlarged view is given in Fig.

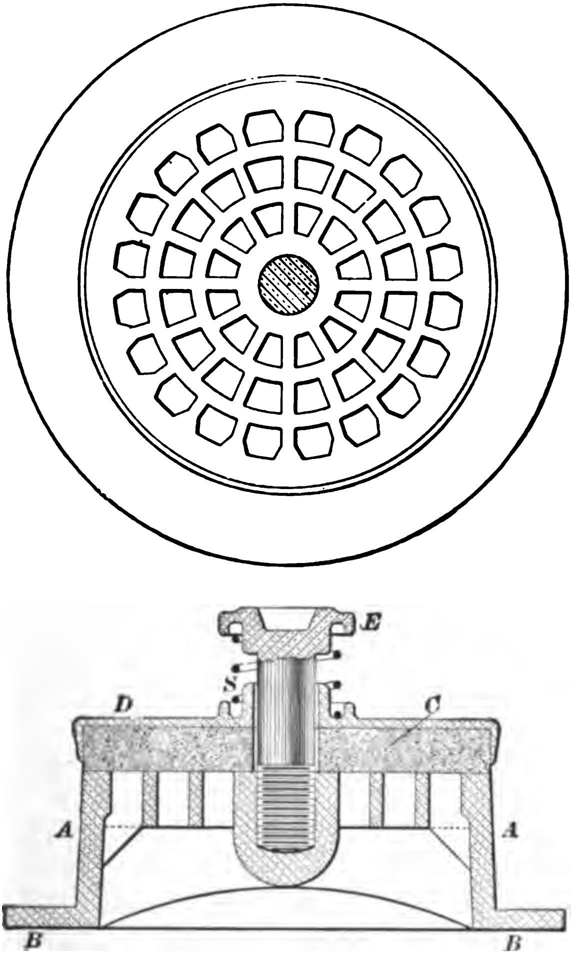


Fig. 785.

785. The valve-seat A is held in place by means of the flange B (see also Fig. 784). As shown in the top view, the valve-seat is perforated by a large number of small holes; this is necessary, since the valve C is made of rubber. The

cap D is made of gun-metal; the spring S and bolt E of phosphor-bronze.

Another pump of this description and of the same make is in actual use near Wilkes-Barre, Pa., working against a head of 1,060 feet. It is a **22″ and 36″ × 9″ × 36″ compound duplex;** that is, the high-pressure cylinder, low-pressure cylinder, and plungers are respectively 22″, 36″, and 9″ in diameter, and the stroke is 36″.

2258. Fig. 786 shows a **Knowles compound condensing outside-packed duplex mine-pump.** The arrangement of the high and low pressure cylinders and of the plunger-cylinders is similar in all respects to the pump described in Fig. 783, and, hence, will not be repeated here.

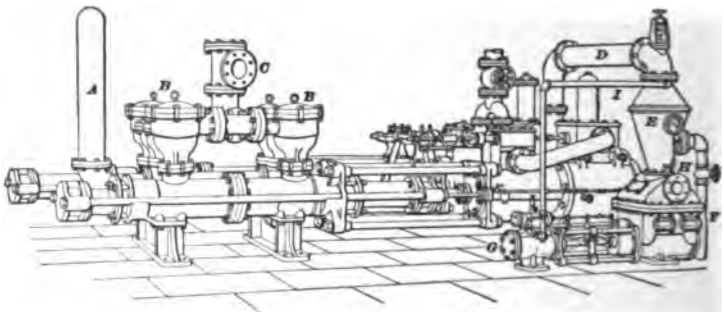


FIG. 786.

There are four discharge-valves—one for each plunger-cylinder. The suction-valves are not seen in this view. A is one end of the suction-pipe, the other end being in the sump from which the water is taken. This pipe lies between the two sets of water-cylinders, and has communication with all of the four plunger-cylinders. The discharge-valves B are what the makers term "**pot-valves**"; they are claimed to be of great durability, and work on independent gun-metal composition seats. Both valves and seats can be easily taken out and examined. C is the flange to which the discharge-pipe is bolted. After the steam has been used in the low-pressure cylinder, it is discharged into a condenser E through the pipe D. After being condensed, the water

is discharged through a pipe bolted to the flange *H*. *F* is the pipe which leads the cold water to the condensing-chamber *E*. *G* is the air-pump for removing the condensed water and discharging it either into the boiler, if placed near the pump, or into the sump. *I* is a pipe through which the exhaust steam from the air-pump passes to the condenser.

These pumps are intended for very heavy duty, the one shown in the cut being designed for a discharge of 1,000 gallons per minute under a head of 800 feet. They will pump water vertically 1,000 feet or over on single lifts.

SINKING-PUMPS.

2259. When putting down a new shaft or deepening an old one, the so-called **sinking-pump** is used to drain the water from the shaft-bottom, so that the work may proceed. These pumps must necessarily be portable, and are suspended by a chain attached to eye-bolts in the pump. They are also provided with wrought-iron clamps, by means of which they may be attached to the timbers in the shaft when it is desired to fix them in position temporarily. Hence, as the shaft gets deeper, the chain may be lengthened out, an extra joint placed on the upper end of the delivery-pipe, and it is again ready for business. The sinking-pump is subjected to the hardest usage of any other mine machine. The water pumped is invariably gritty and often acid. The water trickling down on the pump from above carries mud along with it, and so completely covers the pump that it is hardly distinguishable at times from the soil itself. Notwithstanding all this, a sinking-pump must work night and day, often up to the limit of its capacity, and its failure, even for a day, at a critical period, may flood a shaft, which would require a week or more to recover.

2260. In Fig. 787 is illustrated two views of a **Cameron sinking-pump.** This pump meets all of the conditions required of a sinking-pump, and is a favorite with mine operators. There is no outside valve mechanism whatever, and nothing short of actual breakage of the pump

itself, or of the steam, suction, or delivery pipe, can prevent the pump from working. The manner of suspending it from a chain is shown in the cut, also the method of at-

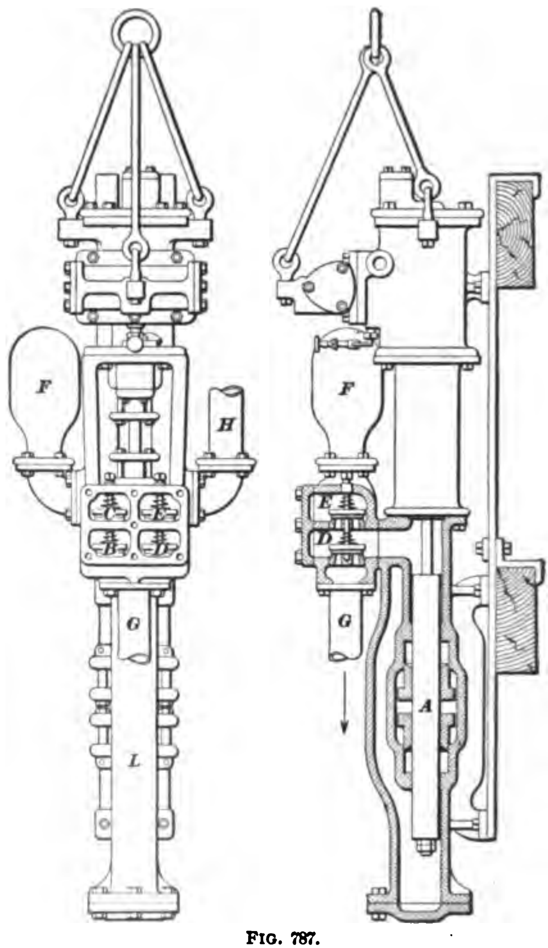


FIG. 787.

taching it to the shaft-timbers. In order to more clearly show the working of the valves and plunger, a partial section of the pump is given in the figure. The pump has one plunger, and is double-acting. Instead of employing a

diaphragm to separate the two plunger-cylinders, as in the pump illustrated in Fig. 784, two stuffing-boxes are placed in the center to accomplish the same purpose. This device is frequently used in ordinary horizontal mine-pumps, and when so used the pumps are called **center-packed,** to distinguish them from the **inside-packed** and **outside-packed pumps.** The center-packed pump is considered superior to the inside-packed pump for mining purposes, but not to be so convenient as the outside-packed pump. The center-packed sinking-pump, however, is considered superior to the other two. The action of this pump is as follows:

G is the suction-pipe and *H* the delivery-pipe. Suppose the plunger to be moving in the direction indicated by the arrow. The water is forced out of the chamber *L*, which communicates with the delivery-pipe *H* by means of the valve *C*, and lifts *C*, thus flowing into *H*. As the plunger moves down it leaves a vacuum behind it; the water in the shaft rushes up the suction-pipe, raises the valve *D*, and fills the upper part of the plunger-cylinder. When the stroke is reversed, the valves *C* and *D* close, and the valves *E* and *B* open, the water being forced up the pipe *H*, through the valve *E*, and the chamber *L* is filled through the opening of the valve *B*. *F* is, of course, the air-chamber. The section shown by the view on the right is taken in a rather peculiar manner, the greater part being taken through the center line of the engine, so as to show the plunger, stuffing-boxes, etc., and the part showing the valves being taken on the center line of the valves *E* and *D* of the view on the left.

It is quite customary to use a sinking-pump to raise the water from the sump to the first station, since the sinking-pump may be raised or lowered according to the depth of the water in the sump. A single steam-pipe down the shaft supplies both the sinking-pump and the main pump. When used for this purpose, the sinking-pump exhausts into the sump.

On account of its portability, the sinking-pump is especially adapted to the recovery of flooded mines.

LOCATION OF PUMPS.

2261. Fig. 788 shows a partial section of a mine. It is intended to illustrate the different positions of the pump, pipes, sump, etc. *A* is the sump, or a reservoir filled by means of a sinking-pump raising the water to *A* from a sump below, and *B* is a compound condensing duplex pump. *C* is the condenser and air-pump. *D* is the steam-pipe which is carried down the shaft to the pump. *D'* is a smaller steam-pipe, leading from the main pipe *D* to the air-pump which it drives. *E* is the pipe which connects the condenser

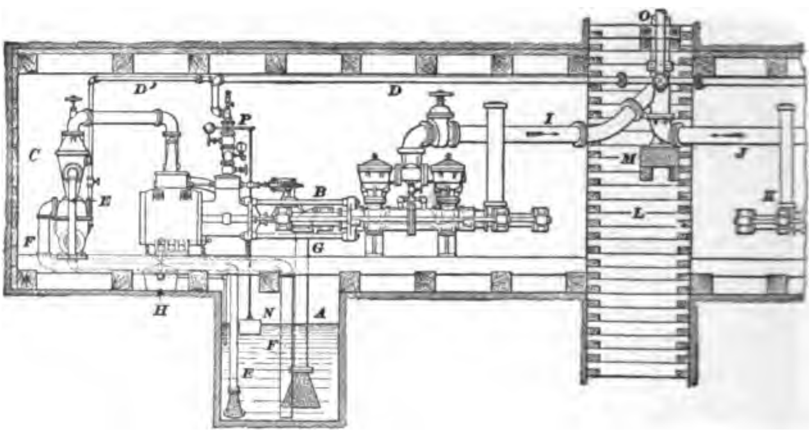


FIG. 788.

with the sump; it supplies the cold water needed for condensing the steam. This water is conveyed to the condenser on the same principle that the water flows through the suction-pipe of a pump. The steam is condensed, and leaves a partial vacuum in the condensing-chamber; the atmospheric pressure forces the water in the sump up the pipe *E*. After the steam delivered by one stroke of the pump has been condensed, the condensed steam, together with the water used to condense it, is pumped back into the sump through the pipe *F*. It is evident that the colder the injection water, the better will the condenser perform its duty. Consequently, in order to enable the pipe *E* to obtain as cold water as possible, the pipe *F* discharges very

close to the pump suction-pipe *G*. *H* is a steam-trap for the purpose of removing entrained water and water of condensation from the steam before entering the pump. *I* is the delivery-pipe which connects directly with the column-pipe *O* (main delivery-pipe) in the shaft *L*. *N* is a float

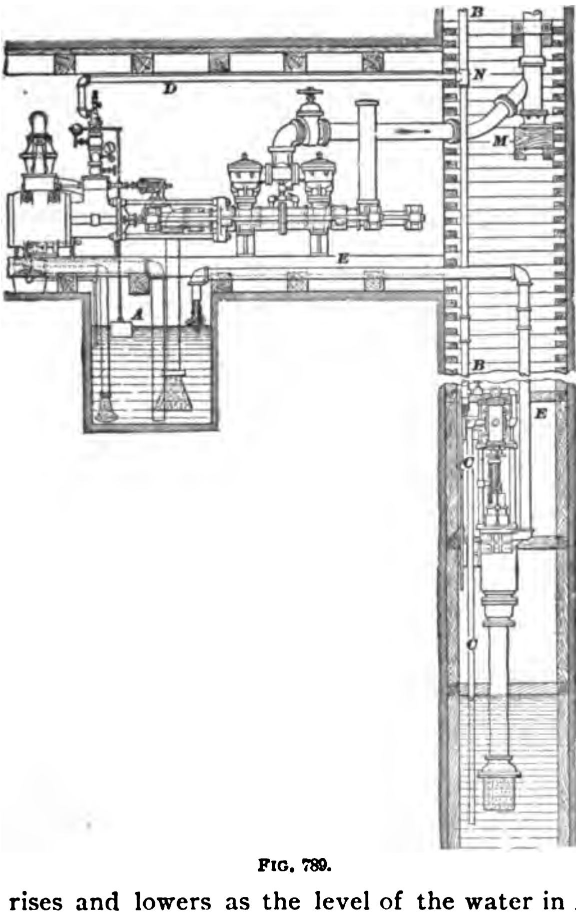


FIG. 789.

which rises and lowers as the level of the water in *A* rises and lowers. This action operates a balanced throttle-valve *P* on the steam supply-pipe. Should the water in the sump become too low, the float falls so far that the engine stops automatically. The movement of the float up or down also

governs the speed of the engine. *K* is an extra pump to be used in case it should be desirable or necessary to shut the other down. Its delivery-pipe *J* discharges into the same column-pipe *O* as shown. It is an excellent plan to have duplicate sets of pumps. There is then no need of stopping work should one of the pumps be disabled.

It will be noticed that the column-pipe is supported by a cast-iron stand, which rests upon the timbers *M*. This arrangement is shown more clearly in Fig. 789.

2262. Fig. 789 shows a pumping plant similar to the one described previously, except that only one pump is used, and a sinking-pump is employed to raise the water from the bottom of the shaft to the tank *A*. This arrangement is used when it is desired to sink a shaft below the level on which the pump stands, and the lift is too great for the sinking-pump to raise the water to the surface. As will be noticed, both pumps receive their steam from the same pipe *B*, which runs straight up the shaft to the surface. This pipe is covered with some material that is a non-conductor of heat, to reduce the loss of steam through condensation, and to prevent the men from getting burned by accidentally touching it when working in the shaft. The exhaust steam-pipe *C* of the sinking-pump discharges into the sump. *E* is the sinking-pump discharge-pipe. *B* is the steam-pipe; it supplies both the sinking-pump and the main pump by means of a **T** joint *N* and the pipe *D*. The manner of supporting the column-pipe is very clearly shown at *M*.

THE PULSOMETER.

2263. One of the most ingenious of the various machines operated by steam is the **pulsometer.** Fig. 790 shows a perspective view and Fig. 791 a sectional view of a pulsometer of the latest manufacture. In the sectional view the full lines represent the left-hand half, and the dotted lines indicate the position of the discharge-valves in the right-hand half of the pulsometer shown in Fig. 790. In the following description, the letters refer to both figures:

The steam-pipe is connected at *E* and the suction-pipe at *S*. *C* is an air-chamber, which has no connection with *B* and *A*, but communicates with the suction-pipe by means of the opening *I*, situated below the suction-valves *F* and *G*. The two latter valves are made of flat rubber, and are held to their seats, as shown in the cut, by means of the spindles *R* and *T*. The spindles are raised and lowered, as the case may require, by means of the nuts *f* and *e*. *H*, *H* are plates which may be removed to facilitate the examination of the valves. *D* is a hard-rubber ball, which acts as a valve for admitting the steam to the chambers *A* and *B*. *M* and *N* are exhaust-valves, also made of rubber, and situated in the chamber *L*, attached to the other half of the cylinder. They are raised and lowered in the same manner as the suction-valves, by turning the nuts *g* and *h*. *K* is the delivery or column pipe.

2264. The action of the pulsometer is as follows: Both chambers, *A* and *B*, are filled with water to about the height of the water in *B*, Fig. 791. The valve *d* is then opened, and the steam enters one of the two chambers *A* and *B*. Suppose it enters *B*, the valve *D* being at the right, as shown. The water in *B* will be forced through the delivery-valve *N* into and up the column-pipe *K*. This will continue until the water-level gets below the edge of the discharge-opening *P*. At this point the steam and water mix in the discharge-passage, and the steam is condensed, creating a vacuum in *B*. The pressure in *A* is now greater than in *B*, owing to the vacuum in *B*, and the ball-valve *D* is shifted to the left, the steam entering the chamber *A*, and driving the water through *M* into the passage *O* and column-pipe *K* in the manner just described. While this is being done, the pressure of the atmosphere forces the water up the suction-pipe *S*, opening the suction-valve *F*, and into the chamber *B*, filling it. When the suction-valve is closed, owing to the reshifting of the ball-valve *D* to the other side, the suction-water enters the air-chamber *C* through the inlet *I*, and is brought gradually to rest by the

compression of the air in C, thus preventing a shock, owing to the sudden stoppage of the inflowing water. When the water in A has reached the level shown, the steam in A is

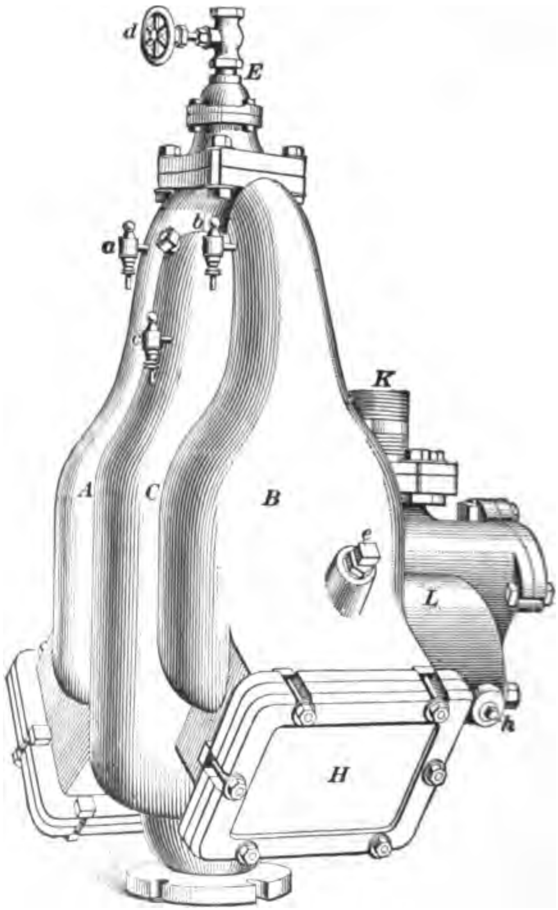


FIG. 790.

condensed, the ball D is shifted to the right, and B becomes the driving-chamber.

2265. In Fig. 790 are shown three small air-valves a, b, and c. The valve c admits air to the air-chamber C, to replenish that which is lost through leakage and through

absorption by the water. The valves *a* and *b* admit a small quantity of air to the chambers *A* and *B*, respectively, just before the suction begins. This injures the suction somewhat, but is necessary for two reasons: *First*, it acts as a

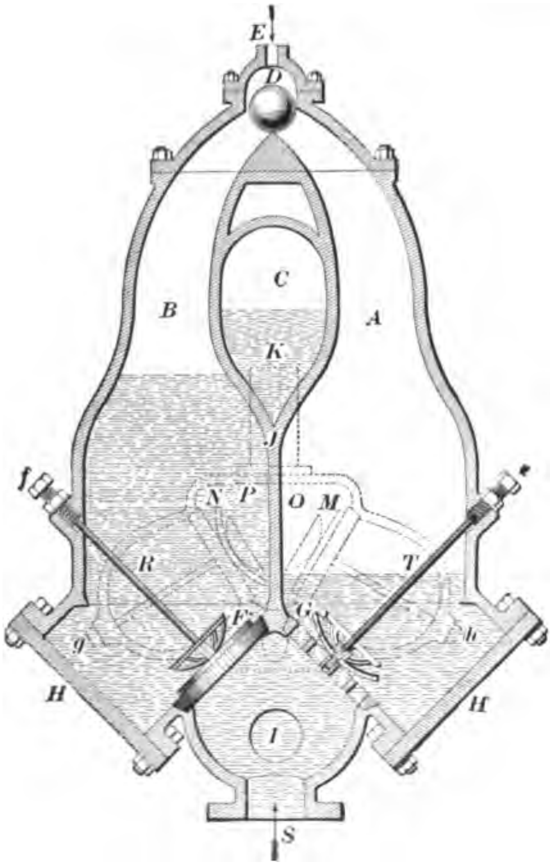


FIG. 791.

regulator, governing the amount of water admitted to the chambers. *Second*, it prevents the steam from condensing before the water gets below the edge of the discharge-outlet. These valves open inwards, as before stated. Suppose there is a vacuum in *A*, owing to the condensation of the steam. The atmospheric pressure forces open the valve *a* and admits

a little air to the cylinder. The incoming water compresses this air, and soon closes the valve. When the air has been compressed to such an extent as to balance the outside pressure of the atmosphere, the suction-valve G will close, and no more water can get in. Since the same thing occurs in the other chamber, it is evident that the amount of air admitted controls the amount of water admitted during the suction period, more water entering when there is less air in the chamber, and *vice versa*. The admission of the air is controlled by turning the valves a and b, and these can be so adjusted that the suction-valve in either chamber will close at the instant the ball is shifted to the other side, admitting the steam.

Moreover, the air prevents the steam from coming in contact with the water during the forcing process, until the water-level has sunk below the edge of the discharge-orifice. Air being a poor conductor of heat, the steam does not condense until the mixture of the steam and water has taken place.

2266. The pulsometer will raise water by suction to a height of about 26 feet, although it is not advisable to exceed 20 feet, and force it, when necessary, to a height of 100 feet. It has no wearing parts whatever except the valves, which are easily and cheaply repaired. It will work in almost any position, and, when once started, requires no further attention. There are no parts which can get out of order. It will pump anything, including mud, gravel, etc., that can get past the valves. Its first cost is low, and it requires no foundations to set up. There is no exhaust-steam to make trouble, and no noise. It uses more steam than a pump, its duty being from 7,000,000 to 10,000,000 foot-pounds per 100 pounds of coal. One of the leading pump manufacturers of this country states that the *average* duty of single steams is from 15,000,000 to 20,000,000; of compound pumps about 30,000,000, and of compound condensing-pumps about 50,000,000 foot-pounds per 100 pounds of coal burned.

ELECTRIC PUMPS.

2267. All of the pumps heretofore described for underground mine work have been steam-pumps. The simple pump, both single and duplex, can be run by means of compressed air. As mentioned before, there are several ways by which the pumps may be driven other than by the use of steam. Of late, the electric pump is being used to some extent, and will, perhaps, in time, displace steam-pumps for underground mine use.

2268. A cut of an electric pump is shown in Fig. 792. It is what is termed a **triplex pump;** that is, there are three cylinders side by side, all three being operated at the same time from the same shaft *A*. *B* is the motor, the electric current being conveyed to it by two wires from a dynamo at the surface. As the motor revolves, it turns with it the shaft to which is keyed the pinion *C*. *C* gearing with *D* causes *D* to turn the pinion *E*, keyed to the same shaft as *D*. *E* gearing with *F* revolves the crank-shaft *A*, and with it the cranks *G*, *H*, and *I*, which impart a reciprocating motion to their plungers *L*, *K*, and *J*. These cranks are set at angles of 120° with each other, and the plunger-cylinders all discharge into the same delivery-pipe *M*, the consequence being that a nearly uniform discharge is secured, much better than that attained in the duplex construction, which is itself superior, in this respect, to the single pump. *N* is the suction-pipe. These pumps are made to raise water in single lifts from 400 to 800 feet, and to deliver at the point of discharge from 50 to 450 gallons per minute, according to size. In combination with these pumps, a small pump, called the **tail-pump,** is generally used to deliver the suction water to the main pump under a slight pressure, thus insuring the plunger-cylinder being full before the commencement of the return stroke.

The pump illustrated is termed a **horizontal triplex electric pump.** In many cases they are made vertical; that is, the plungers move vertically instead of horizontally. They are also made both triplex and duplex; the latter

type being applicable, with some modifications, to the ordinary duplex steam-pump, the steam-cylinders being replaced by the motor.

It is necessary, in order that the motor be effective, that it revolve at a high speed, while the crank-shaft must turn

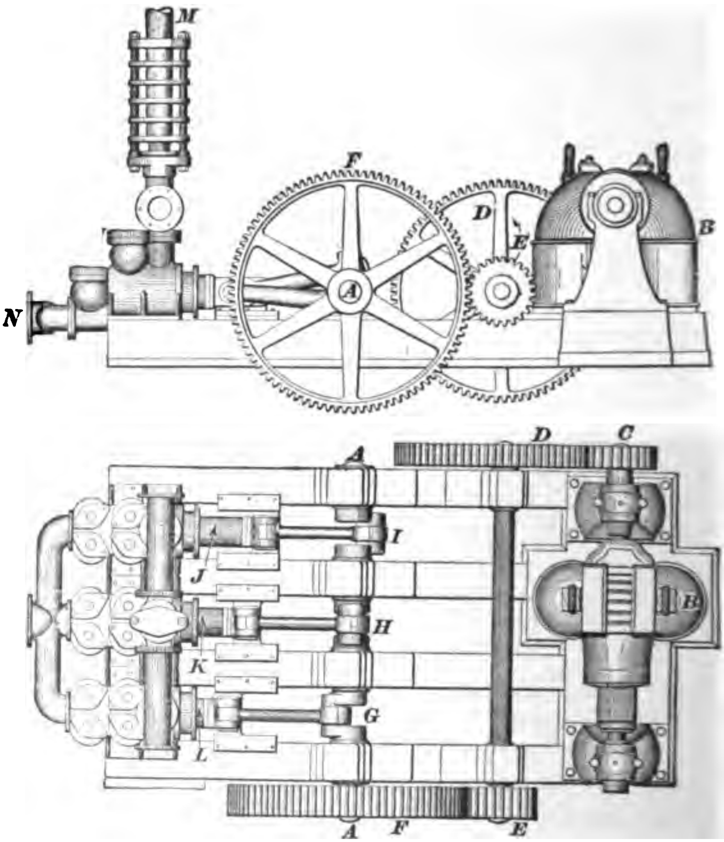


FIG. 792.

at a low speed; it is for this reason that the motion of the motor is transmitted to the crank by means of gearing. In Fig. 792 the gear D is about 3 times as large as the pinion C, and F about $3\frac{1}{2}$ times as large as E; hence, the motor revolves $3 \times 3\frac{1}{2} = 10\frac{1}{2}$ times while the gear F, and, conse-

quently, also the crank-shaft A, is revolving once. Therefore, if the crank-shaft A makes 50 revolutions per minute, the motor will make $50 \times 10\frac{1}{2} = 525$ revolutions per minute.

2269. Fig. 793 shows a **duplex electric sinking-pump.** E and F are the two plunger-rods, the plungers themselves being central-packed, as shown at H; D is the clamping-piece for attaching the pump to the shaft-timbers, and G the eye-bolt for suspending it from a chain. A is the discharge-pipe; B, the suction-pipe, and C, the air-chamber. The only visible moving parts are short portions of the plungers and rods at H and E. No damage whatever can come to this pump from the water. It will work just as well under water as out of it. The only objection on this score that can be urged against it is, that the wires which conduct the electricity to it may be broken by the falling debris. If proper care be exercised, this should not happen. They will raise water vertically 200 feet, and discharge from 100 to 300 gallons per minute, according to size.

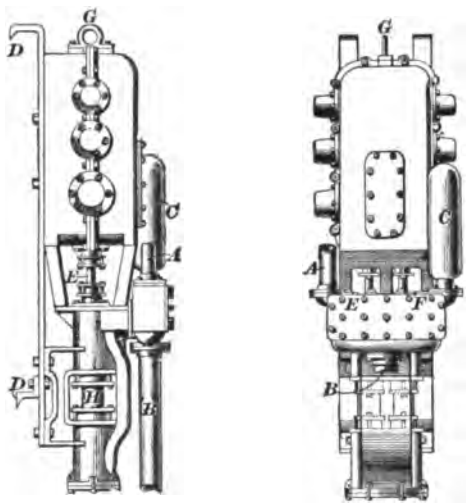


FIG. 793.

2270. A cut of a **water-power electric pumping-plant** is given in Fig. 794. A is a sinking-pump, which raises the water from the lowest level to the first station, discharging through the pipe C into the tank B. From this station, the water is raised to the next higher one by means of, in this case, a **vertical triplex pump,** and so on by one or more lifts to the surface. The wires which conduct the electricity down the shaft are enclosed in a small iron pipe

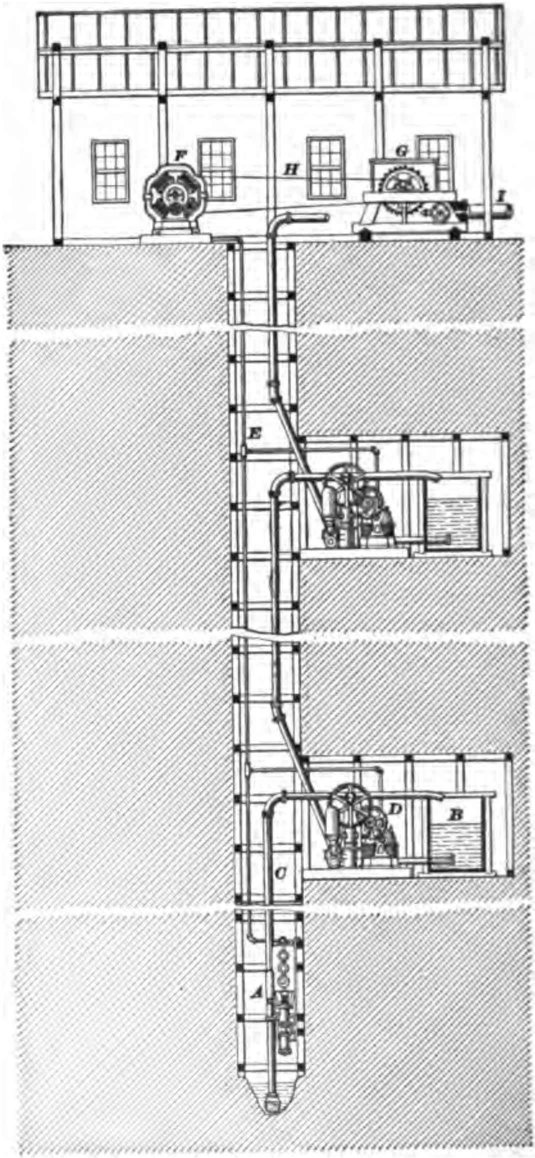


FIG. 794.

E, to prevent injury. *F* is the dynamo. *G* is a **Pelton water-wheel,** the water being conducted to it through the pipe *I*, and the power generated transmitted to the dynamo by means of the belt *H*. It will, of course, be understood that a water-wheel can be used as a motive power only when a natural head is available. It would not be advisable to put in a plant of this kind for a head of less than, say, 40 or 50 feet. In case a water-wheel can not be used, a steam-engine can be employed to drive the dynamo.

Instead of vertical triplex pumps, horizontal triplex or duplex pumps may be used; they take up more room than the vertical type, and hence are not so convenient where space is required.

HYDRAULIC PUMPING-ENGINES.

2271. It frequently happens in connection with mines that water accumulates at a point below the level of the water in the sump, and at a considerable distance from it, which it is necessary to pump to the surface. The distance from the main pump may be half a mile or more, and the expense of putting in a small pump, and conducting steam and exhaust pipes to it, is out of all proportion to what it would be under more advantageous conditions. In such cases as this, **hydraulic engines** are used. The principle under which they operate is, that a small quantity of water falling from a great height will raise a larger quantity to a smaller height.

2272. Before explaining the theory of the engine, the engine itself will be described, so as to make the theory easier to understand. Fig. 795 shows a hydraulic engine, the motor-cylinder *A* being shown in section. There are two valves, *B* and *C*, which are made of lignum-vitæ. *P* is the piston that drives the pump *E*, which may be of ordinary construction. *F* is an air-chamber on the discharge-pipe. *G* is a flange for bolting the suction-pipe to the pump. *H* is another flange for attaching the discharge-pipe. *T*, *T* are doors, which may be removed to allow examination of the

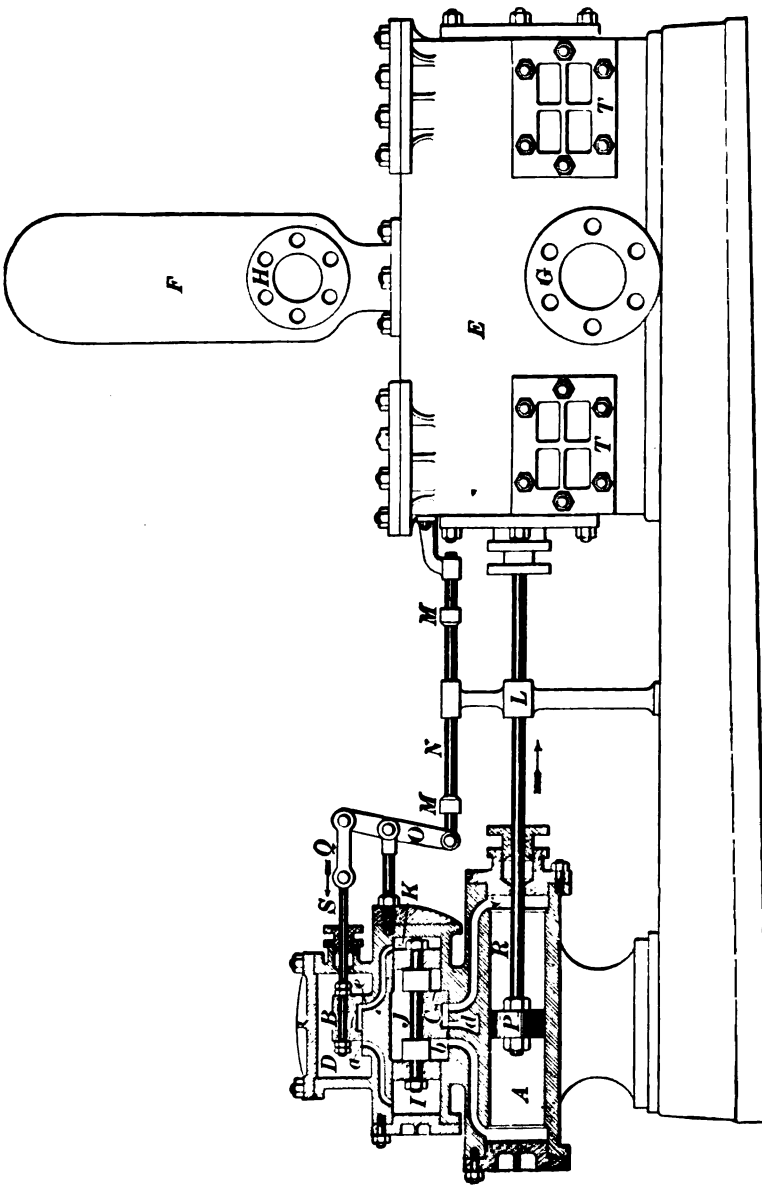


FIG. 795.

suction-valves. Suppose the piston, valves, etc., to be in the position shown. The water which drives the engine fills the chest *D*, and has the full pressure due to its head; it passes through the port *a* into the space *I*; there is also a communication with the main valve-chamber *J* from which the water passes through the port *b* into the cylinder, and drives the piston in the direction of the arrow. Attached to the piston-rod is an arm *L*. When the piston nears the end of its stroke to the right, the arm *L* strikes the lug *M*, and causes the rod *N* to actuate the lever *O*, one end of the lever being attached to the rod *N*, and the other end to the valve-stem *S*, by the link *Q*. The valve *B*, pressed equally by the water on both ends, is caused to be moved to the left, opening the port *e*. The water in the chest *D* then enters the space *K*, and causes the valve *C* to be moved to the left, forcing the water confined in the space *I* through the port *a* and the under side of the valve *B* into the pipe which conducts away from the pump the water discharged through the exhaust-port *d*. To better understand this last statement, suppose the piston to be at the end of its stroke to the left, and that the arm *L*, striking the lug *M*, has shifted the valve *B* to the right, as shown in the cut. The valve *C* will also move to the right, for the reasons before given, and the water in the space *K* will be forced through the port *e* and under the valve into the water exhaust-pipe.

2273. In the case of hydraulic-engine pumps, the motor-piston *P* is always smaller than the pump-piston, but the length of stroke of both pistons is the same. If there were no friction or other resistance than that due to the weight of the water, the areas of the two pistons would be inversely proportional to the heads acting upon the pistons; that is, if a be the area of the motor-piston (*P* in Fig. 795), A the area of the pump-piston, h the head which acts upon the pump-piston, and h_1 the head against which the pump works (height of lift), the following proportion expresses the relation between them:

$$a : A :: h_1 : h.$$

The amount which the pump will be required to discharge is usually known; also the heads h and h_1. The discharge being known, the length of the stroke and area of pump-piston can be so taken that the volume displaced by the piston in one stroke, multiplied by the number of required strokes per minute, shall be equal to the required discharge. When this has been done, the values of A, h_1, and h will be known, and a can be found from the proportion just given.

EXAMPLE.—Suppose that the head of water which acts upon the motor-piston is 640 feet, and the pump is required to discharge 80 gallons of water per minute under a head of 120 feet, what are the diameters of the motor and pump pistons, the length of their strokes, and the number of strokes per minute?

SOLUTION.—Since one cubic foot of water contains 7.48 gallons, the number of cubic feet in 80 gallons would be $\frac{80}{7.48} = 10.695$ cu. ft. For a pump of this kind, it would be well not to have the piston speed exceed 80 feet per minute. Assume the number of strokes per minute to be 60, then the amount of water displaced in one stroke is $10.695 \div 60 = .17825$ cu. ft. $= .17825 \times 1{,}728 = 308$ cu. in. If the stroke be taken as 10 in. long, the area of the pump-piston will be $308 \div 10 = 30.8$ sq. in., and the diameter will be $\sqrt{\frac{30.8}{.7854}} = 6\frac{1}{4}$ in., nearly. Ans.

The piston speed will evidently be $\frac{60 \times 10}{12} = 50$ feet per minute. As this is well within the limit advised (80 feet per minute), it may be used, and, in case the pump should be required to deliver more than 80 gallons per minute at any time, the speed can be increased to meet the demand. To find the diameter of the motor-piston, first find the area by the proportion given above. In this case, $h = 640$, $h_1 = 120$, and $A = 30.8$; hence,

$$a : 30.8 :: 120 : 640, \text{ or } a = \frac{30.8 \times 120}{640} = 5.775 \text{ sq. in.}$$

The diameter, consequently, equals $\sqrt{\frac{5.775}{.7854}} = 2\frac{3}{4}$ in., nearly. Ans.

The values just calculated are theoretical values; the friction of the water in the pipes and the leakage past the piston will modify the results to a considerable extent; consequently, when calculating the sizes of a hydraulic pumping-engine, employ the method given in the latter part of this section, using formulas **190** to **196**.

In this arrangement, the water used in the motor-cylinder has to be raised again to the point where the pump discharges, and from there to the surface.

2274. Fig. 796 shows a hydraulic engine operated in a different manner, which is said to give excellent results, and may be worked as easily under water as out of it, should the mine be flooded. The motor-cylinder does not discharge the water remaining in the cylinder after the stroke is completed, into the sump, as described in the last figure, but uses the water over again, as the following description will show: *A* is a steam-engine, whose piston-rod *T* passes through the steam-cylinder *Q*, and also through two single-acting pump-cylinders *I* and *R*. The hydraulic engine is located at the bottom of the mine; it consists of two single-acting motor-cylinders *F* and *G*, and two single-acting pump-cylinders *H* and *S*. A small pipe *D* connects the pump-cylinder *I* with the motor-cylinder *G*, and another pipe *E*, of exactly the same size, connects the pump-cylinder *R* with the motor-cylinder *F*. *B* is a tank which contains sufficient water to charge the pipes *D* and *E*. *J* is the suction-pipe which conducts the water to the pump, and *K* is the column-pipe which delivers it to the surface.

2275. The action of the apparatus is as follows: Suppose that the pipes *D* and *E* are empty. The cock *U* is opened, and the water flows from the tank *B* until the pipes *D* and *E* are filled. The cock *U* is then closed, and the engine started. Let the engine be moving in the direction indicated by the arrow on the fly-wheel; the pistons in the cylinders *Q*, *I*, and *R* will then be moved towards the left. The piston in the cylinder *I* will force the water in *I* through the pipe *D* into the cylinder *G*. The piston in *G* is connected with the pistons in *S*, *H*, and *F* by means of the long piston-rod *W*. The pressure of the entering water against the piston in *G* forces it and the other three pistons in *S*, *H*, and *F* to the left. This action forces the water in the cylinder *H* through the discharge-valve *P* into the column-pipe *K*, causing it to discharge at *Y*. The vacuum

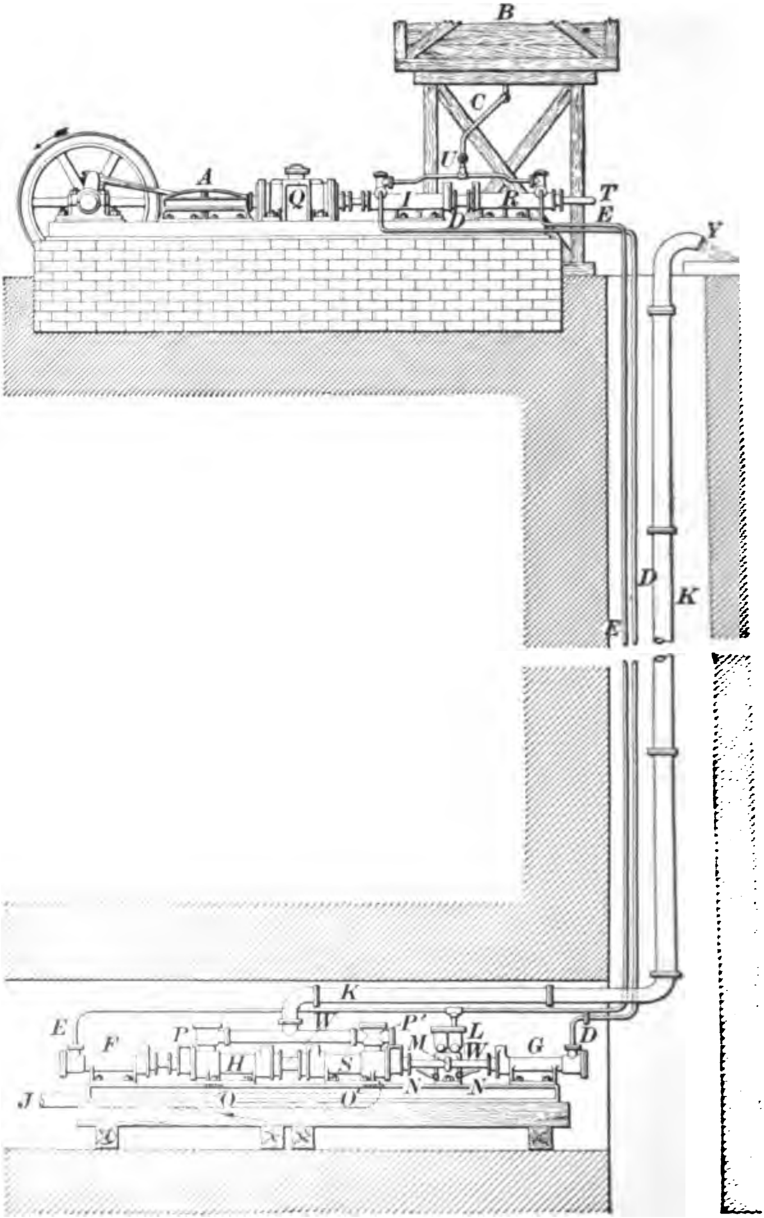


FIG. 796.

created in S by this movement of the piston in S to the left causes the water to enter the suction-pipe J, and flow through the suction-valve O' into the cylinder S. The water in front of the piston in the cylinder F is forced out through the pipe E into the cylinder R, to fill the vacuum created in R owing to the movement of the pistons to the left. When the stroke of the engine is changed to the right, all of these various movements are reversed. The water is forced out of the cylinder R, through the pipe E, into the cylinder F, thus forcing the pistons in H, S, and G to the right. The water is then drawn through J into H, and forced out of S into K, the water in G being forced out of G through D into I.

When the pipes D and E have once been filled, there will be no necessity of replenishing them with water, except to make up the loss occasioned by evaporation or leakage at the joints and past the pistons. In order to guard against any harm resulting from this leakage, and thus having more water in one of the pipes than in the other, relief-valves are situated at L; these valves are operated by the levers N, N, which are themselves operated by the lug M, on the piston-rod striking the end of one of them and forcing it downwards, opening one of the two valves, and allowing the two pipes D and E to communicate with each other, thus equalizing the pressure of the water on both sides of the piston in one of the motor-cylinders and stopping it. The piston-rod T projects through the cylinder R, in order that there shall not be more water on one side of the piston in R than on the other side. The piston speed of the pumps in this arrangement should not exceed 80 feet per minute, nor the speed in the pipes D and E 300 feet per minute. For this reason, the engine must run very slowly, or else must be geared so that the speed of the pistons shall not exceed 80 feet per minute. It will, of course, be understood from the above description that the water in the pipes D and E merely conveys the force exerted by the steam-engine piston in Q to the pump-cylinders H and S. This method of conveying the power of the steam to the pumps is much

cheaper than in the case of direct-acting steam-pumps, and is said to give a higher efficiency than either compressed air or the electric wire.

Although the pumps may be used for lifts as high as 1,200 feet or more, the best results are obtained when the lift is about 600 feet. The pressure in the pipe *D* and *E* is usually about 1,000 pounds per square inch.

2276. Relative Merits of Underground Pumps.— The steam-pump is the most used of all the different classes of pumps, but, nevertheless, there are serious objections to its use. In the first place, there is apt to be considerable loss due to the transmission of steam through long distances, as from the boilers at the surface to the pumps, perhaps half of a mile or more. This is remedied to a great extent by covering the pipe with some non-heat-conducting material. This increases the first cost quite materially, and renders it difficult to locate any leak that may occur without removing a considerable portion of the covering. If the boilers are placed underground, near the pumps, the subsequent heat and gaseous products of combustion are a serious obstacle. But the greatest objection is what to do with the exhaust-steam. There are three ways of disposing of it: convey it to the surface through a pipe laid for that purpose; lead it into the sump, or discharge it into the upcast shaft.

2277. When the pumps exhaust into the sump, it is often found that the whole body of water is heated to a comparatively high temperature, raising the temperature of the mine and increasing the humidity of the air to such an extent that the mine-timber decays with ruinous rapidity, and, at some collieries, the roof and coal on the airways, gangways, and travelingways are softened, and become both troublesome and dangerous. A partial remedy for this would be to condense the steam, as shown in Fig. 788, before discharging into the sump. Were this done, and the discharge-pipe located very near the pump suction-pipe, as

mentioned in connection with the figure, it is probable that the above-mentioned objections would disappear.

When the exhaust is conveyed to the surface through a pipe of considerable length, trouble is caused by the condensation of steam in the pipe, and also by the radiated heat. This condensation decreases the efficiency of the pump by increasing the back-pressure. The practice of conveying the exhaust into the upcast is often ruinous to the walls, roof, and timbering of the upcast passage.

In addition to the above, steam-pumps are useless when drowned out, either through breakage or sudden flooding. This risk can be remedied by having a surplus pumping capacity and reserve pumps in readiness.

All of the above objections can be eliminated by the use of compressed air in place of steam. Its efficiency is considerably less than that of steam, particularly when compound pumps are used.

2278. The use of electricity in connection with mine-pumps is so recent that it would be inadvisable to recommend it to replace any steam or compressed-air plant now in operation. In the near future, it is probable that it will supersede all other means of raising mine-water to the surface wherever new workings are being opened. The capability of the dynamo to be driven by both water-wheel and steam-engine, and the ease and efficiency with which the electric power can be transmitted to any point, as well as its comparatively low first cost, render this conclusion inevitable. Electric pumps will run equally as well under water as out of it—a great advantage in the case of a drowned-out mine.

SIPHONS.

2279. In many cases, water collects at some point in a mine higher than the level of the water in the sump or other place where it is desired to convey it. If there is an incline all the way, it may be conducted by means of a drain-pipe by gravity; but it frequently happens that, in order to

F. II.—16

reach the sump, the water must be conveyed over a point higher than the level at the source, and it is not expedient to cut a passage through the high ground in order that the water may flow down by gravity. In such cases, siphons may be used.

2280. The principle of the siphon is illustrated in Fig. 797. Here *A* and *B* are two vessels, *B* being lower than *A*, and *A C B* is the bent tube, or siphon. Suppose this tube to be filled with water and placed in the vessels as shown, with the short branch *A C* in the vessel *A*. The water will flow from the vessel *A* into *B* as long as the level of the water in *B* is below the level of the water in *A*, and the level of the water in *A* is above the lower end of the tube *A C*. The atmospheric pressure upon the surface of *A* and *B* tends to force the water up the tubes *A C* and *B C*. When the siphon is filled with water, each of these pressures is counteracted in part by the pressure of the water in that branch of the siphon which is immersed in the water upon which the pressure is exerted. The atmospheric pressure opposed to the weight of the longer column of water will, therefore, be more resisted than that opposed to the weight of the shorter column; consequently, the pressure exerted upon the shorter column will be greater than that upon the longer column, and this excess pressure will produce motion.

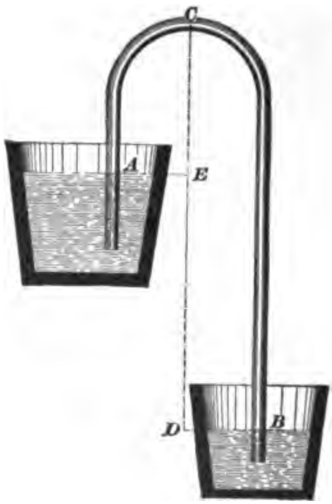


FIG. 797.

2281. In any siphon, the head which causes the flow of water is equal to the vertical distance between the two water-levels which the siphon connects; in the above figure, the head equals the distance *E D*. Theoretically, the distance *C E* of the highest point of the center of the pipe above the

level of the water into which the short leg of the siphon dips may be 34 feet; practically, 28 to 30 feet is the highest that a siphon will work successfully. If required to work continuously, 21 feet should be the greatest height of *C E*. The less this distance is, the better the siphon will work. There is no limit to the distance *E D* which constitutes the head.

2282. Fig. 798 shows a siphon working in a mine. It is desired to convey the water from *D* to *E*, the level of the water in *E* being always lower than in *D*. The siphon consists of ordinary cast-iron pipe, jointed, and three valves, *A*, *B*, and *C*. The suction end of the pipe is the same as the end

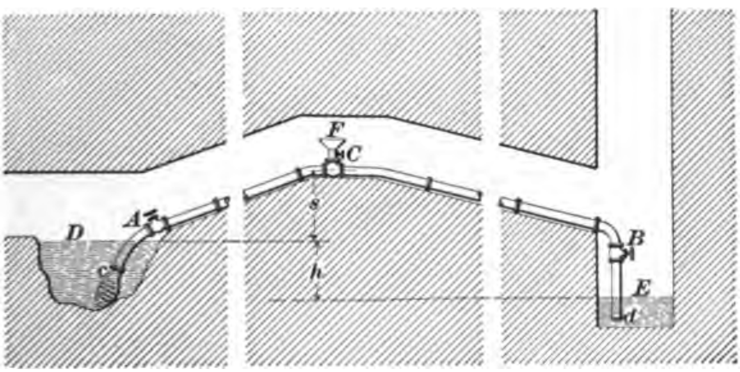


FIG. 798.

of the suction-pipe of a pump; i.e., it has a perforated pear-shaped end, in order to keep out large particles, which would prevent the siphon from working. In order to start the siphon, it is necessary to remove the air in the pipe. This is accomplished by closing the valves *A* and *B*, and opening the valve *C*. Water is then conveyed to the funnel *F* and poured in. The water drives the air out, and takes its place in the pipe. When no more water can be poured in without overflowing at *F*, the valve *C* is closed, the valves *A* and *B* are opened, and the siphon is in operation.

The distance *s* between the highest point of the center of the pipe and the lowest level of the water in *D* must not exceed 28 feet; it would be better not to have it exceed 21 feet.

The greater the distance h between the two water-levels, the better the siphon will work.

Instead of filling the pipe with water in order to remove the air, an air-pump may be attached at C and the air pumped out. When this is done, and both ends of the siphon are submerged in water (as they should always be in practice), the valves A and B are left open, the water gradually rising in the pipe as the air is removed, and finally appearing at C; the valve C is at once closed, and the siphon begins to work.

2283. Fig. 799 shows a very convenient method of filling the pipe with water when the siphon discharges into the

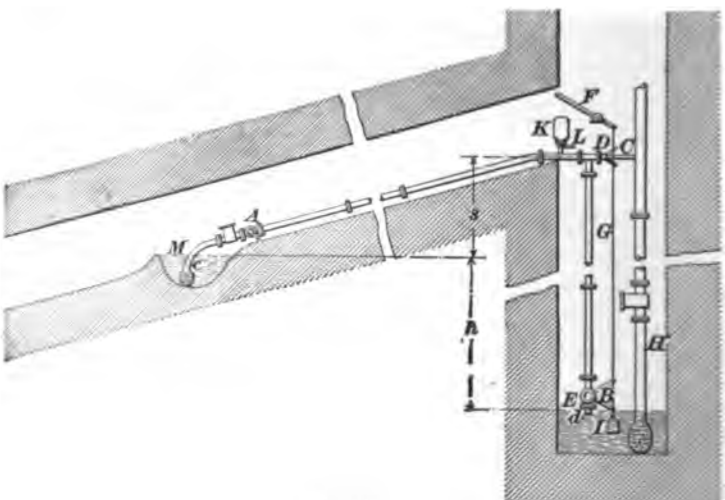


FIG. 799.

sump. Here M is the point from which it is desired to siphon the water, E is the sump, s is the height of suction, and h is the head which induces the flow. A is the valve at the suction-end, and B the valve at the delivery-end. H is the column-pipe of the main pump, C a small pipe leading from the column-pipe to the siphon, communication being opened or closed by aid of the valve D. K is a chamber to allow the air to escape, and L is a valve which controls the communi-

cation between the siphon and the chamber. All four valves, *A*, *B*, *D*, and *L*, are operated by handles, as shown. In order to keep the air from getting past the valve *L* when it is closed, thus entering the pipe and destroying the action of the siphon, the chamber *K* is kept filled with water. The lever *F* has fastened to its short arm a rod *G*. Attached to this rod are the handles of the valves *B* and *D*, and to its lower end the weight *I*. When in the position shown, the valve *B* is open and *D* is closed. In order to start the siphon, the valve *A* is closed and *L* is opened. The lever *F* is then pulled down. This action raises the handles of the valves *D* and *B* to the position shown by the dotted lines, opening the valve *D* and closing the valve *B*. The water flows into the siphon from the column-pipe through the small pipe *C*. When the siphon is filled, the water appears at chamber *K*, the valve *L* is closed, the lever *F* is released, and the weight *I* pulls it back into the position shown in the cut, closing the valve *D* and opening the valve *B*. The valve *A* is then opened, and the siphon is in working condition.

2284. In order that a siphon shall work properly, it is necessary that air should be kept out of the pipe, or, if it gets in, means should be provided for its escape. Air will enter the

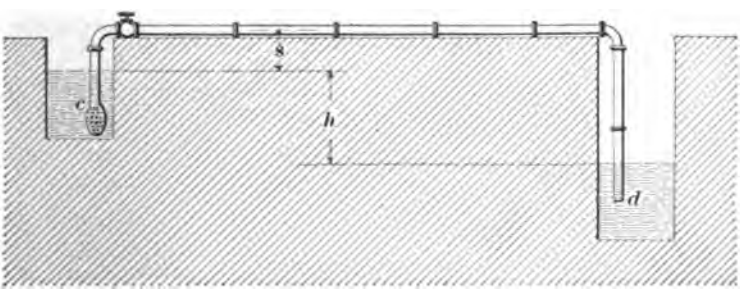


FIG. 800.

pipe in spite of all precautions, and, when once in, will collect at the highest point of the siphon because the pressure there is least. The joints must be perfectly air-tight; even then the water absorbs air, which is given out again as the

pressure lessens. Then, too, the pipe seldom runs full continuously, and air enters the pipe with the water unless both ends of the pipe are submerged in water. Since the air always seeks the highest point of a siphon, sharp bends at this point, as at E, Fig. 801, should in all cases be avoided. A long bend, as in Fig. 798, a straight level pipe, as in Fig. 800, or a pipe on a long incline, as in Fig. 799, will always work well.

2285. A siphon with a sharp bend, as in Fig. 801, will not work well, for the following reasons: As before stated, the air seeks the highest point, which is E. This air is at once compressed to an amount represented by difference

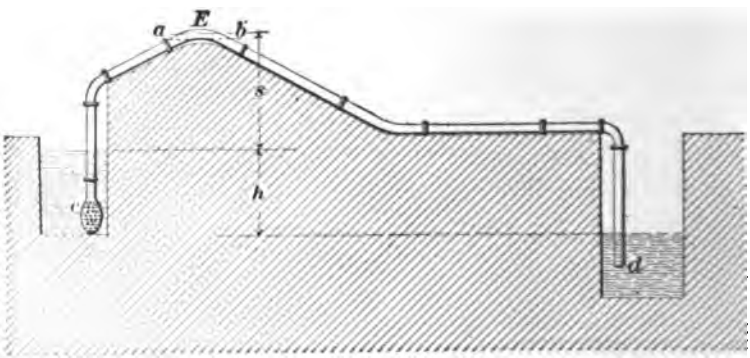


FIG. 801.

in pressures of a column of water whose height is s (in feet) and 34 feet (the height of a column of water which the atmosphere will support). Suppose that in the figure $s = 22$ feet; then the tension of the air at E would be $34 - 22 = 12$ feet of water $= 12 \times .434 = 5.208$ pounds per square inch. This pressure will not be materially increased by the addition of a little more air, which, consequently, goes to increase the volume of the air already there. When the volume becomes sufficient to occupy the space $a\,E\,b$, the dotted line $a\,b$ representing a horizontal line just touching the bottom of the inside of the pipe, the water can not get through the bend, and the siphon is useless. The same is

also true of a siphon having a double bend, as shown in Fig. 802. Here the air will collect at E and F—at E first,

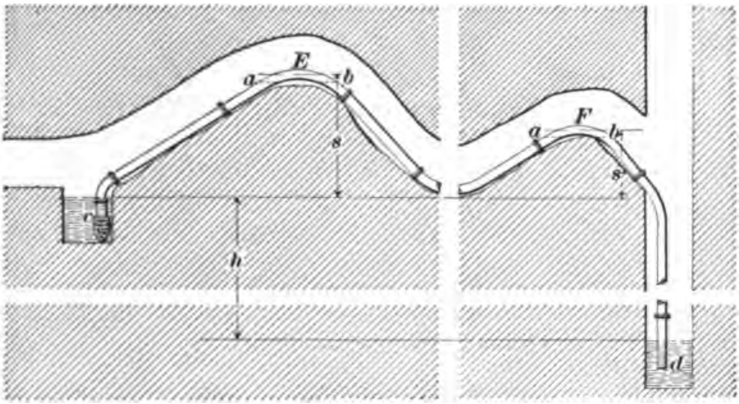


FIG. 802.

and F afterwards. This is an extremely bad construction, and should in all cases be avoided.

2286. A device which will remedy the bad action of a siphon to a considerable extent, by removing the air, is shown in Fig. 803. Here A is an air-tight vessel connected

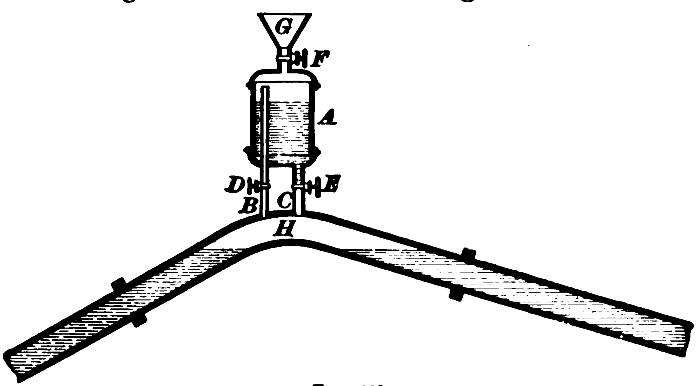


FIG. 803.

with the siphon by two pipes, B and C. The pipe B extends to very nearly the top of A, while the pipe C barely enters the bottom. Each pipe has a valve, D and E. On the top

of the vessel are a funnel *G* and valve *F*. When the air has collected in the siphon and ceased its flow, the valves *D* and *E* are closed, and the valve *F* is opened. Water is then poured into *A* until it is filled and overflows the funnel *G*. The valve *F* is closed and *D* and *E* opened. Water will flow down through *C*, and the air will ascend through *B*, until the air is all out of the pipe. This being done, *D* and *E* are shut and *F* opened. The vessel is then filled with water, *F* is shut, *D* and *E* are opened and left open. Any air which enters the siphon will, instead of collecting at *H*, seek the highest point by ascending *B*, and forcing out a certain amount of water through *C*. This will continue until *A* is filled with air, when the valves *D* and *E* should be shut, and the vessel *A* refilled, as before described. This arrangement may also be used to fill the siphon for the purpose of setting it to work. It is, of course, evident that the highest point of the water in *A* must be not more than 28 feet above the level of the water at suction.

2287. Theoretically, it makes no difference whether the discharge-end of a siphon is submerged or not, but practically it does, for the reason that, if the siphon is not flowing full, the air will enter and work its way to the highest point, unless the discharge-end is beneath the water. It also makes no difference if one end of the siphon is larger than the main pipe. On the contrary, it is rather an advantage to have the suction-end funnel-shaped, since the resistance encountered by the water on entering is thereby lessened. A siphon will work better using cold water than when using warm water; hence, it works better in the winter than in the summer

2288. The amount of water which a siphon will discharge is calculated by the formulas given for the discharge of a pipe. The head is, in all cases, the distance marked *h* in Figs. 798 to 802, and the length *l*, used in the formulas, is the whole length of the siphon from the end of the suction-end to the end of the discharge-end. In finding the head *h*, it is assumed that the discharge-end is submerged ; then the

head is the vertical distance in feet between the level of the water at suction and the level of the water at discharge. If the discharge-end is not submerged, the head will be the vertical distance between the level of the water at the suction and the end of the discharge-pipe. It makes no difference how far below the water the ends of the siphon may extend. The two ends of the siphon may, in fact, be level. The head is measured as described, and the direction of the flow will always be from the higher to the lower *water-level.* The length of the pipe is, in all cases, measured from *c* around to *d.*

EXAMPLE.—A siphon has a total length of 1,420 feet; its diameter is 4 inches, and the distance between the water-levels is 38 feet. What is the discharge in gallons per hour?

SOLUTION.—It is first necessary to find the velocity by formula **182.** Thus, $v_m = 2.315\sqrt{\frac{hd}{fl}} = 2.315\sqrt{\frac{38 \times 4}{.025 \times 1{,}420}} = 4.79$ ft. per sec.

From Table 45, $f = .023$ for $v_m = 4$, and $.0214$ for $v_m = 6$; difference $= .023 - .0214 = .0016$ for a difference of 2 feet per second in the velocity $= .0016 \div 2 = .0008$ for a difference of 1 foot per second in the velocity. $4.79 - 4 = .79$. $.0008 \times .79 = .000632 =$ amount to be subtracted from .023 to give the value of f for $v_m = 4.79$. Hence, $f = .023 - .0006 = .0224$, using but four decimal places. Substituting the values of f, l, h, and d in formula **186,**

$$Q = .09445\,d^2\sqrt{\frac{hd}{fl + .125\,d}} = .09445 \times 4^2\sqrt{\frac{38 \times 4}{.0224 \times 1{,}420 + .125 \times 4}} =$$

3.2778 gal. per sec. $= 3.2778 \times 60 \times 60 = 11{,}800$ gal. per hour, very nearly. Ans.

CALCULATIONS PERTAINING TO PUMPS.

2289. To find the pressure in pounds per square inch corresponding to any given head of water:

Rule.—*Multiply the head in feet by .434; the result is the pressure in pounds per square inch.*

2290. To find the head of water corresponding to a given pressure in pounds per square inch:

Rule.—*Multiply the given pressure in pounds per square inch by 2.304; the result is the head in feet.*

EXAMPLE.—What pressure will a head of 120 feet of water exert?

SOLUTION.—Applying the first rule,

$$120 \times .434 = 52.08 \text{ lb. per sq. in. Ans.}$$

EXAMPLE.—What head of water will exert a pressure of 65 lb. per sq. in.?

SOLUTION.—Applying the second rule,

$$65 \times 2.304 = 149.76 \text{ feet. Ans.}$$

2291. To find the size of the plunger-cylinder to discharge a given number of gallons per minute:

Let G = number of gallons discharged per minute;
S = plunger speed in feet per minute;
d = diameter of cylinder in inches.

Then,
$$d = 4.95\sqrt{\frac{G}{S}}.$$

Since, however, there is always more or less slip of the water past the plungers, it is usual to add $\frac{1}{4}$ of the required number of gallons to the value given to G in the above formula, to allow for this slip. Doing so, the formula becomes

$$d = 5.535\sqrt{\frac{G}{S}}. \qquad \textbf{(190.)}$$

Formula **190** should always be used when calculating the size of the plunger-cylinder to discharge a certain number of gallons per minute. The piston speed is the number of feet traveled per minute by the plunger when forcing water; that is, it equals the length of the stroke in feet multiplied by the number of working strokes per minute. If the pump is double-acting, the number of working strokes is the same as the total number of plunger-strokes, both forward and back; if single-acting, half of that number.

EXAMPLE.—What should be the diameter of a pump-plunger required to discharge 130 gallons of water per minute, the speed of the plunger to be 115 feet per minute? If the pump is double-acting and the stroke is two times the diameter, how many strokes must it make per minute, and what is the length of the stroke?

SOLUTION.—Applying formula **190**,

$$d = 5.535 \sqrt{\frac{G}{S}} = 5.535 \sqrt{\frac{130}{115}} = 5.88 \text{ in., say, } 5\tfrac{7}{8} \text{ in. Ans.}$$

Since the stroke is twice the diameter,

$$\text{stroke} = 5\tfrac{7}{8} \times 2 = 11\tfrac{3}{4} \text{ in.} = \frac{11.75}{12} \text{ ft. Ans.}$$

$$\text{Number of strokes} = 115 \div \frac{11.75}{12} = \frac{115 \times 12}{11.75} =$$

117.44 strokes per minute, nearly. Ans.

This speed is rather high for a pump, and should be employed only when absolutely necessary.

2292. To find the approximate discharge in gallons per minute of a mine-pump, when the diameter and plunger speed are known, use the following formula:

$$G = .03264\, d^2 S. \qquad \textbf{(191.)}$$

The same allowance has been made for the slip in this formula that was made in formula **190.** If the theoretic discharge is required, $G = .0408\, d^2 S$.

EXAMPLE.—What is the probable discharge of a duplex double-acting mine-pump whose plungers are 10 inches in diameter, stroke 24 inches, and which makes 40 strokes per minute?

SOLUTION.—Applying formula **191**,

$G = .03264\, d^2 S = .03264 \times 10^2 \times (2 \times 40) = 261.12$ gal. per min., since 24 in. $= 2$ ft. and the piston speed $= 2 \times 40$ ft. per min. The total discharge is twice this amount, or

$$261.12 \times 2 = 522.24 \text{ gal. per min. Ans.}$$

EXAMPLE.—In the above example, what is the theoretic discharge?

SOLUTION.— $G = .0408\, d^2 S = .0408 \times 10^2 \times (2 \times 40) = 326.4$ gal. per min. $326.4 \times 2 = 652.8$ gal. per min. Ans.

2293. To find the horsepower of a steam or air cylinder to discharge a certain number of gallons of water per minute with a given lift, substitute in the following formula, in which $H =$ the number of horsepower, $h =$ vertical height in feet between the highest point of the center of the delivery or column pipe and the level of the water in the sump or place from which it was taken, and $G =$ the number of gallons discharged per minute:

$$H = .00038\, G\, h. \qquad \textbf{(192.)}$$

The theoretic horsepower will be two-thirds of the above result

EXAMPLE.—How many horsepower should the steam-cylinder of a pump be designed for which is required to discharge 350 gallons per minute, the total lift being 320 feet?

SOLUTION.—Applying formula **192**,

$H = .00038\,G\,h = .00038 \times 350 \times 320 = 42.56$ horsepower. Ans.

In the above example, the theoretical horsepower is $42.56 \times \frac{2}{3} = 28.37$ horsepower. In formula **192**, allowance has been made for friction of water in the pipe, engine friction, pump friction, etc.

2294. If it is desired to know the height which a pump will raise water, when the horsepower of the steam-cylinder and discharge of the pump have been determined, use the following formula, in which the letters have the same meaning as in formula **192**:

$$h = \frac{H}{.00038\,G}. \qquad \textbf{(193.)}$$

EXAMPLE.—To what height will a 40-horsepower pump force 280 gallons of water per minute?

SOLUTION.—Applying formula **193**,

$$h = \frac{H}{.00038\,G} = \frac{40}{.00038 \times 280} = 376 \text{ feet. Ans.}$$

2295. To find the size of the steam or air cylinder of a pump, first calculate the horsepower by formula **192**, then proceed as follows: It is customary to design pumps on a basis of 100 feet plunger speed per minute. For mine-pumps working continuously, this is about right, although in some cases as high as 240 feet per minute has been attained. Nevertheless, for continuous working, 100 feet per minute is a fair allowance, and does not bring excessive strains on the pump. If a simple pump is to be used, the mean pressure of the steam or air will be the same as the gauge pressure at the pump, since the pressure is carried full stroke. If the pump is also direct-acting, the speed of the steam-piston will be the same as the pump-piston or plunger speed.

Let S = piston speed;
D = diameter of cylinder in inches;
r = ratio between the length of stroke and diameter of cylinder;
l = length of stroke in feet;
N = number of strokes per minute;
H = horsepower;
P = steam or air pressure per sq. in.

Then, $$D = 205\sqrt{\frac{H}{PS}}. \qquad \textbf{(194.)}$$

The diameter may also be found by formula **148**, *Air and Air Compression*, Art. **2152**.

$$D = 79.6\sqrt[3]{\frac{H}{rPN}}.$$

Having obtained the diameter by means of either formula **148** or formula **194**, the stroke can be found by multiplying the diameter by the value of the ratio r. In case formula **194** is used, the number of strokes can be found by dividing the piston speed by the length of the stroke in feet.

Example.—A pump to be driven by compressed air, at a pressure of 45 pounds per square inch, is to have a piston speed of 100 feet per minute. If 32 horsepower are required to operate it, what should be the size of the air-cylinder and the number of strokes?

Solution.—Using formula **194**,

$$D = 205\sqrt{\frac{32}{45 \times 100}} = \sqrt{\frac{42{,}016.8 \times 32}{45 \times 100}} = 17.285 \text{ in., or say } 17\tfrac{1}{4} \text{ in.}$$

For this case, let the stroke be, say, 22 in., thus making r a little over $1\tfrac{1}{4}$. The number of strokes will then be $100 \div \frac{22}{12} = 54\frac{6}{11}$. To make even figures all around, let the number of strokes be 55 per minute. Ans.

Since it is easier to extract square than cube root, the first of the above formulas is to be preferred to the second.

SIZES OF SUCTION AND DELIVERY PIPES.

2296. The usual practice is to allow a velocity of 200 feet per minute in the suction-pipe, and 400 feet per minute in the delivery-pipe. Substituting these values for S in the formula for the theoretical diameter of the plunger given in

Art. **2291,** and letting d_1 be the diameter of the suction-pipe and d_2 the diameter of the delivery-pipe,

$$d_1 = 4.95\sqrt{\frac{G}{200}}, \text{ or } d_1 = .35\sqrt{G}. \qquad \textbf{(195.)}$$

$$d_2 = 4.95\sqrt{\frac{G}{400}}, \text{ or } d_2 = .25\sqrt{G}. \qquad \textbf{(196.)}$$

The pipes may be larger than the values calculated by the above formulas, particularly the suction-pipe, but it is not a good plan to make them any smaller. The larger the pipes are, the less the velocity, and, consequently, the less the frictional resistances.

EXAMPLE.—What should be the diameters of the suction and delivery pipes of a pump which discharges 225 gallons of water per minute?

SOLUTION.—Applying formula **195,**

$$d_1 = .35\sqrt{G} = .35\sqrt{225} = 5.25 \text{ in.}$$

Since the pipe sizes usually vary by even inches above 4 in. diameter, the size of the suction-pipe should be either 5 in. or 6 in. diameter, preferably the latter, but assumed for this case to be 5 in. Also $d_2 = .25\sqrt{225} = 3.75$ in., or say 4 in. diameter. Hence, the diameters are, respectively, 5 in. and 4 in. Ans.

Some manufacturers make the diameters of their suction-pipes equal to the diameter of the plunger.

EXAMPLE.—Calculate the sizes of the steam and water cylinders and of the suction and delivery pipes for a direct-acting steam-pump to discharge 770 gallons of water per minute, under a head of 1,000 feet, single lift, the steam-pressure at the pump to be 71 pounds per square inch.

SOLUTION.—Assume for this case a plunger speed of 120 feet per minute. Then, using formula **190,**

$$d = 5.535\sqrt{\frac{G}{S}} = 5.535\sqrt{\frac{770}{120}} = 14.05 \text{ in., say 14 in.,} = \text{diameter of plunger.}$$

Assuming the stroke to be three times the diameter of the plunger, the stroke $= 14 \times 3 = 42$ in. Since the pump is direct-acting, the stroke of the steam-piston must also be 42 in. The number of strokes per minute will be $120 \div \frac{42}{12} = 34\frac{2}{7}$. The horsepower is found by means of formula **192.**

$$H = .00038\,G\,h = .00038 \times 770 \times 1{,}000 = 292.6 \text{ horsepower.}$$

The diameter of the steam-cylinder is found by formula **194.**

$$D = 205\sqrt{\frac{292.6}{71 \times 120}} = 38 \text{ in., very nearly.}$$

Diameter of suction-pipe, $d_1 = .35\sqrt{G} = .35\sqrt{770} = 9.712$ in., say 10 in.

Diameter of delivery-pipe, $d_2 = .25\sqrt{770} = 6.937$ in., say 7 in.

Hence,

Diameter of plunger,	14 in.	Ans.
Diameter of steam-cylinder,	38 in.	
Diameter of suction-pipe,	10 in.	
Diameter of discharge-pipe,	7 in.	
Stroke of pump,	42 in.	
Number of strokes per minute,	$34\frac{2}{7}$.	
Horsepower,	292.6.	

EXAMPLE.—Find the sizes of a duplex pump to fulfil the same conditions given in the last example, assuming the stroke to be about $2\frac{1}{2}$ times the diameter of the plunger, and the steam-pressure to be 76 pounds per square inch.

SOLUTION.—The total horsepower and the diameter of the discharge-pipe (common to both) will be the same as before. Each pump-cylinder will discharge $\frac{770}{2} = 385$ gallons per minute.

Hence, applying formula **190,**

$$d = 5.535\sqrt{\frac{385}{120}} = 10 \text{ in., very nearly.}$$

Stroke $= 10 \times 2\frac{1}{2} = 25$ in., say 24 in., or 2 ft.

The number of strokes per minute $= 120 \div 2 = 60$.

Horsepower of each steam-cylinder $= \frac{292.6}{2} = 146.3$.

Applying formula **194,**

$D = 205\sqrt{\frac{146.3}{76 \times 120}} = 25.9$ in., the diameter of the steam-cylinder, say 26 in.

The suction-pipes each deliver 385 gallons per minute to the pump; hence, applying formula **195,**

$$d_1 = .35\sqrt{385} = 6.87 \text{ in., say 7 in.}$$

Consequently,

Diameter of plungers (2),	10 in.	Ans.
Diameter of steam-cylinders (2),	26 in.	
Diameter of suction-pipes (2),	7 in.	
Diameter of discharge-pipe (1),	7 in.	
Stroke of pump,	24 in.	
Number of strokes per minute,	60.	
Horsepower of each cylinder,	146.3.	
Total horsepower,	292.6.	

2297. Starting a Pump.—See that the pump is well oiled, and that all pipes and connections are free from obstructions; see that the stuffing-boxes and plungers are properly packed. Open the charging and relief pipes, to fill the suction and cylinders with water and drive out the air; also, open the drain-cocks of the steam-cylinder. Before starting, allow the steam-cylinder to warm up thoroughly. Turn on the steam gradually, and run the pump at slow speed for a short time.

Failure of a pump may be due to a multiplicity of causes, the chief of which are the following: Air in the pump-chamber or in the suction-pipe; dirt in the suction-pipe or in the valves; suction-pipe too long or too small and crooked; air-chamber too small; leaky steam-valves or warm pistons or plunger; pump hot and filled with vapor; improper design of pump for the work to be done.

The greatest difficulty met with in pumping mine-water is the chemical action of the water upon the pump-cylinders, plungers, rods, valves, etc. It is particularly destructive in the anthracite coal regions. Portions of old mine-pumps are seen in which some of the cast-iron parts were so soft that they could be easily cut with a knife. They have the appearance of a honeycomb. Other instances have been frequently noted where the water has dripped on a steel rail from the roof of a mine, and eaten a hole through it. When the mine-water is in this condition, the life of a pump is short at the best. The exposed cast-iron parts are made of the hardest cast iron that can be worked. The water will attack wrought iron and steel even quicker than cast iron. This chemical action is much less rapid on gun-metal, phosphor-bronze, and several other alloys; hence, in well-constructed pumps for raising acid water of this kind, the valves are made of this material when not made of rubber. In cases of this kind, and also when the water is very gritty, the cylinders are bored larger than the plunger, and a gun-metal or phosphor-bronze shell, about an inch thick, is inserted. The wear comes principally on the bottom, and when it has worn more than desired there, the shell can be turned partly around, so that the wear may come at another point. When worn out, the plunger and shell can be replaced, and the old shell melted up.

A SERIES

OF

QUESTIONS AND EXAMPLES

Relating to the Subjects
Treated of in This Volume.

It will be noticed that the various Question Papers that follow have been given the same section numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until the Instruction Paper having the same section number as the Question Paper in which the questions or examples occur has been carefully studied.

ECONOMIC GEOLOGY OF COAL.

(705) Why should practical men have a knowledge of the earth's strata which do not contain coal?

(706) Were the strata we now find inclined ever in a horizontal position? Answer fully, and give reasons for your answer.

(707) Define "conformable," as used in geology.

(708) (*a*) Name the seven ages in the earth's history. (*b*) On what are they founded?

(709) What are false coal measures?

(710) (*a*) Has any regular order of succession been found among coal beds? (*b*) Is there any fixed superposition of the rocks forming the coal measures?

(711) On what do the varieties of coal depend?

(712) Is anthracite a metamorphic rock? Answer fully.

(713) How does change of temperature affect exposed rocks, and what is the result?

(714) How are igneous rocks distinguished from stratified rocks? Answer briefly.

(715) (*a*) Has any coal been found in strata of Silurian Age? (*b*) Would you expect to find workable seams of coal in rocks of this formation in America?

(716) How does the purity of coal support the *in situ* theory?

(717) What action produced the vegetable accumulation from which coal was formed?

(718) If you recognize a trilobite in Fig. 375, give its number.

(719) Give the rule for determining the amount of displacement of a fault.

(720) (*a*) What are fossils? (*b*) How can a knowledge of them be obtained?

(721) (*a*) What class of rocks is thickest in the Appalachian coal field? (*b*) What class of rocks is thickest in the western coal fields of North America?

(722) Are the anthracite and bituminous coals of Pennsylvania the same deposit? Answer fully.

(723) In what epoch did the trilobites shown as Nos. 9 and 10, Fig. 374, exist?

(724) What is the name given to designate the eroded crest of an anticlinal axis?

(725) Is coal ever found below igneous rock? Can you give an instance?

(726) In what age did insects first appear?

(727) What would be the probable temperature of strata, in degrees Fahrenheit, at a depth of 900 feet?

(728) (*a*) Name the two modes of determining and limiting eras, ages, periods, etc. (*b*) Name the five grand divisions in geology, not by their names, but by what their names signify.

(729) (*a*) Name the North American coal fields that belong to the Carboniferous Age. (*b*) Which are productive?

(730) Which is the great limestone period in the Devonian Age in America?

(731) (*a*) To what epoch does the mountain limestone belong? (*b*) To what epoch does the millstone grit belong?

(732) (*a*) In what respect does the Permian differ from the Carboniferous Proper? (*b*) Does it contain coal?

(733) Is a stratum formed during the same period, shale in one place and limestone at another a short distance away? Answer fully.

(734) What is a dyke?

(735) Do anticlinals always form the higher ground?

(736) When there is discordance between the two modes of determining and limiting eras, ages, periods, etc., which of the two methods should be followed?

(737) What effect has piication on the nature and texture of the coal within the affected district?

(738) Are there any valuable coal beds above the Laramie?

(739) Did any of the fossil species found in the Silurian Age exist in any later geological time?

(740) Are any trilobites found above the Devonian Age? Judge from the figures.

(741) What age contains the earliest known fauna?

(742) (*a*) Of what materials and how are conglomerates formed? (*b*) What is breccia?

(743) How did boulders get into coal seams?

(744) Name the most valuable deposit of coal found in the Sub-Carboniferous.

(745) What is the difference between a butt cleat and a bedding plane?

(746) What is the shape of most coal fields? Give reasons.

(747) If the line *a b*, Fig. 356, measures 1,000 feet and the angle of dip is 70°, what will be the thickness of the strata, provided there is no fault?

(748) To what do you attribute the columnar appearance of some lava?

(749) State briefly the source and mode of growth of coal seams.

(750) (*a*) Has any coal been found in the Devonian Age? (*b*) Would you expect to find coal of workable thickness on the American continent in strata of this age?

(751) What classes of fossils predominate in the Devonian Age?

(752) Does the manner of accumulation of the material forming coal beds differ in the Jura-Trias from that in the Carboniferous? Answer fully.

(753) Do any of the species, genera, or families of the Devonian Age now exist ?

(754) Name the forces of denudation.

(755) How much may the amount of displacement of a fault vary ?

(756) If there is any evidence that stratified rocks are more or less consolidated sediments, state it. Answer briefly.

(757) Can the coal measures (Carboniferous) rest on any other strata than the Devonian ? Answer fully.

(758) How many of the known fossil species of plants belong to the coal measures ?

(759) Name the States in which thin workable seams of coal have been found in the Sub-Carboniferous.

(760) (*a*) Which natural agents exert mechanical force ? (*b*) Which agents cause chemical change ?

(761) When strata dip in opposite directions from a ridge, by what name is the ridge known ? Answer fully.

(762) What is a geological formation ? Answer fully.

(763) What is the difference between plutonic and volcanic rocks ?

(764) (*a*) What is a pot-hole ? (*b*) Mention a disaster caused by a pot-hole.

(765) In what form are the coal plants principally found, and in what part of the seam or adjacent strata ?

(766) How do you account for a limestone roof over coal ?

(767) How was the order of superposition of rocks determined ? Answer briefly.

(768) Can the direction of dip be positively known if the direction of the strike is known ? Give reasons.

(769) What strata were formed of the remains of plant and animal life ?

(770) What caused the planes *D*, *D*, *D*, in Fig. 368, Art. **1316**, and what caused the joints *A* and *B* ?

(771) Are there any coking coals in the Laramie-Cretaceous formations ?

(772) Do igneous rocks ever contain fossils ? Answer fully.

(773) (*a*) Sketch a synclinal. (*b*) Can a synclinal be directly under an anticlinal ? Answer fully.

(774) Are any metamorphic rocks found in the Cretaceous formations ?

PROSPECTING FOR COAL AND LOCATION OF OPENINGS.

(775) What is the object of prospecting?

(776) In prospecting a tract of land for coal, what results would induce you to continue or to abandon the search?

(777) In what cases do bore holes give unreliable results as to the commercial value of a seam of coal?

(778) What equipments does a prospector need in the field?

(779) What general indications are furnished by the color of sandstones and shales?

(780) If surface examinations have not shown the presence of coal, even though the exposed strata belong to coal-bearing formations, how is the presence of coal seams proved?

(781) Fig. 804 shows the relative positions of four bore holes. The distance from *No. 1* to *No. 2* is 500 yards; from *No. 2* to *No. 3* is 180 yards, and from *No. 2* to *No. 4* is 320 yards. The line *3* to *4* is at right angles to the line *1* to *2*. A seam of coal is found 180 feet deep in *No. 1*, 260 feet deep in *No. 2*, and 275 feet deep in *No. 3*.

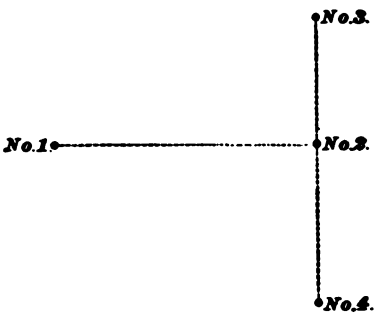


FIG. 804.

(*a*) What will be the depth of the seam in *No. 4*? (*b*) How far back on the line *1* to *2* will you have to go to find the coal at the same depth as in *No. 4*? (*c*) How far must

the line *1* to *2* be prolonged to find the coal at the same depth as in *No. 3*? (*d*) What is the exact dip of the seam? (*e*) Make a drawing to a scale of 300 feet = 1 inch, and show the direction of the dip and also of the strike.

Ans. { (*a*) 233⅓ ft. (*b*) 500 ft. (*c*) 281.25 ft (*d*) 1 in 16.63.

(782) What is meant by triangulation?

(783) What is meant by the calorific power of coal, and upon what constituent does this power depend?

(784) How would you take a sample from a seam of coal that would fairly represent its value?

(785) Explain the nature of rocks which are black in color.

(786) Upon what does the breadth of a coal terrace depend?

(787) A piece of coal weighs 530 grains in air and 105 grains in water; what is its specific gravity?

(788) If in Fig. 405, Art. **1429,** the seam *A A* dips due east at an angle of 46° 20′, and the bore hole *E* is 550 feet from the outcrop, at what depth will this bore hole cut the seam *A A*?

(789) What points should be considered before a tract of land is extensively prospected?

(790) Mention some cases where the condition of the outcrop of a coal seam can give a wrong idea of its true nature.

(791) How would you reduce the size of a sample from a seam of coal in order to obtain a small quantity for analysis?

(792) What indications of the presence of minerals can be found in streams, and what do these indications show?

(793) In what cases is it unprofitable to work a seam of good coal?

(794) Is it ever necessary to sink a number of shafts to properly work a coal seam? If so, explain the conditions.

(795) What is the rule for the position of the beds when the seams dip with or away from the slope of the valley ?

(796) Show by a sketch and explain how you would endeavor to find the outcrop of a coal seam by means of prospect trenches.

(797) What are the limiting angles of intersection of sight lines in triangulation ? Show their size by sketches and explain the sketches.

(798) What are dip and strike faults ?

(799) What is a coking coal, and upon what does this property depend ?

(800) Show by sketch and explain the influence of slip of blossom on thickness of coal seam.

(801) What is the nature of the first examination that a prospector should give a new region ?

(802) If prospect trenches show encouraging yet not sufficient indications, how may the search be continued ?

(803) Explain what is shown by horizontal and by vertical sections.

(804) How is the outcrop of a seam marked on a plan ?

(805) What topographical features are sometimes indications of the presence of coal seams ?

(806) What is the form of the timber used for cribbing girths, and what is the distance between sets ?

(807) The specific gravity of a $4\frac{1}{2}$-foot seam of coal is 1.4; what is the tonnage per acre ? Solve in two ways.

(808) What considerations govern the adoption of the scale to which a preliminary survey should be drawn ?

(809) What is meant by coal blossom ?

(810) In what cases are mines opened by drifts and when by slopes ?

(811) Explain how a spring of water can be due to a fault.

(812) Under what circumstances should a coal field be opened by a shaft, and in what part of the field should the shaft be sunk ?

SHAFTS, SLOPES, AND DRIFTS.

(813) Upon what does the method of opening out a coal field depend ?

(814) Where would you place the shaft in opening out a coal field in which the seam has an inclination of from 3 degrees to 5 degrees, and considerable water is expected ? State your reasons.

(815) State the different ways of opening out a seam of coal, pitching from 45 degrees to 50 degrees, and outcropping well up the mountain side. Also, state which method you believe to be the best under the conditions mentioned.

(816) What are the different forms of shafts, and which is the most prevalent in America ?

(817) Explain how the exact location of a shaft is definitely fixed.

(818) Over what part of a shaft is the temporary hoisting frame erected, and why so placed ?

(819) To what depth is the walling or timbering carried in a shaft ?

(820) Under what conditions are the outside timbers removed as the walling is built up ?

(821) Where should a wedging curb be located in strata producing a great deal of water ?

(822) Why is a shaft sunk below the coal seam ?

(823) Explain the use of supporting curbs.

(824) What is the best kind of bricks for shaft lining ?

(825) How is the lateral pressure distributed equally upon the walling of a shaft?

(826) How many bricks 3 in. by 4 in. by 8 in. will be required to line a circular shaft 16 feet in diameter in which the "hard pan" was struck at a depth of 65 feet? The diameter of the shaft, when finished, to be 15 feet, and 10 per cent. deducted from the number of brick for mortar, etc. Ans. 25,638 bricks.

(827) What is meant by "stripping" a coal seam?

(828) What kind of power is the most economical to use in a shaft, to work drilling machines?

(829) How is the top of a shaft covered while sinking is going on?

(830) When is it necessary to sink a circular shaft?

(831) If, after the "hard pan" is struck and the shaft sunk some distance into the rock, a water-bearing stratum is met, how would you shut off the water?

(832) What are buntons, and how are they fixed in place where timbering is not required?

(833) Upon what does the size of a shaft depend?

(834) What form of shaft would you use where great feeders of water are expected, and how would you shut off these feeders?

(835) Explain the method of carrying off the water where walling is required in a shaft.

(836) How is a shaft ventilated?

(837) What kind of mortar should be used in the walling of a wet shaft?

(838) What are wedging curbs?

(839) What are the advantages of a rectangular shaft in ordinary strata?

(840) What should be the position of the sides of the cage with reference to the pitch of the seam?

(841) What objections are there to opening out a mod-

erately inclined seam by means of a water-level drift or tunnel ?

(842) Give the general points which determine the location of a shaft.

(843) What should be the thickness of cast-iron tubbing in a shaft 15 feet in diameter and at a point 375 feet below the surface ?

(844) How is the water which percolates through the solid strata of a shaft carried off ?

(845) How are the guides arranged for the bucket while sinking a shaft ?

(846) What are the various materials of which shaft walling is made ?

(847) Explain the methods of plumbing a shaft.

(848) In what three ways can quicksand be consolidated sufficiently strong to be excavated by the pick and shovel ?

(849) When are diamond or percussion drills used to advantage in sinking shafts ?

(850) What is meant by sumping holes ?

(851) How would you tamp a hole charged with dynamite in order to get the best results ?

(852) Explain the proper methods of thawing dynamite cartridges.

(853) Aside from tamping the hole properly, what is done to secure the best results when several cartridges are placed in the hole ?

(854) What objections are there to fuse blasting ?

(855) Under what conditions is the churn drill an effective means of boring ?

(856) Describe the method of using the hammer and jumper.

(857) Explain the difference in the methods of exploding black powder and dynamite.

(858) How does ignition take place when an electric current is used in blasting ?

F. II.—48

(859) When should an extra strong exploder be used, and why?

(860) What precaution should be taken while placing a detonator within the cartridge?

(861) What is meant by firing (1) in series? (2) in parallel? (3) in multiple series?

(862) What method of piling would you use to sink through 40 feet of quicksand near the surface?

(863) What is the drum method of sinking?

(864) Describe the Gobert process of sinking through quicksand, using your own language.

(865) What form of piling would you use to sink through a thick bed of quicksand struck some distance below the surface?

(866) Explain Triger's method of sinking.

(867) What difficulties are encountered by sinking by the drum method?

(868) Why is the bottom part of the trepan used in the Lippman method of sinking bifurcated?

(869) What difficulty is there in sinking by the "long hole" method?

(870) Explain fully, and in your own language, the best method of sinking a shaft through hard rock containing water under great pressure.

(871) What advantages are gained by leaving the water in the shaft while sinking by the Kind-Chaudron process?

(872) Explain the process of deepening a shaft where hoisting goes on incessantly.

(873) Describe the method of deepening a shaft where one compartment can be used for hoisting the loose material.

(874) Where should the widening of a shaft be commenced, and what does the process necessitate?

(875) Give the different kinds of guides used in a shaft.

(876) How are the round iron and wire rope guides kept taut?

(877) What is a slope?

(878) What determines the position of the first set of timbers while sinking a slope?

(879) When is piling used in sinking a slope?

(880) What determines the size of a slope?

(881) How are the timbers set with reference to the pitch of the slope?

(882) What should be the batter of a set of slope timbers, and what precautions should be taken in making the joints?

(883) How is the track in a slope kept from slipping down the pitch?

(884) State the form of arch that should be used in a slope where great pressure is expected from all directions.

(885) Explain how the face of a wet slope in a thick seam is arranged and advanced.

(886) What is a drift?

(887) How far below a coal seam dipping inwards 0° 30′ should a drift in which it is desirous to have a grade of $1\frac{1}{2}$ per cent. in favor of the loaded cars be started, the horizontal distance from the drift mouth to the parting to be 200 yards?

Ans. 14.238 feet.

(888) The following data are known: Anticipated depth of shaft, 600 feet; desired tonnage, 1,200 tons per day of 8 hours; inside depth of car, 3 feet; average width of car, 4 feet, and top width, 5 feet; output speed, 36,000 feet per hour. What should be the dimensions of a rectangular shaft of two hoisting compartments and a pumpway 6 feet wide, allowing 1 foot between the side of the car and the buntons, which are 10 inches wide, for clearance, guides, etc., and assuming the broken coal to weigh 50 pounds per cubic foot?

Ans. $\begin{cases} \text{21 ft. 8 in. long.} \\ \text{9 ft. 4 in. wide.} \end{cases}$

METHODS OF WORKING COAL MINES.

(PART 1.)

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(889) What determines the size of shaft pillars?

(890) What should be the general guide in any district in fixing the size of slope or shaft pillars?

(891) A shaft 625 feet deep is surrounded on all sides by buildings, the furthest one from the shaft being 125 feet distant. What should be the size of the shaft pillar?

(892) Why is draw more likely to affect the alinement of a shaft than that of a slope?

(893) Why should slope pillars increase in width as the slope advances downwards?

(894) What conditions of top and bottom require the largest pillars?

(895) State why squeezes frequently occur in slopes.

(896) Where two contiguous seams, separated by 20 or 30 yards of strata, are worked together by the pillar and chamber method, what should be the relative position of the pillars in the two seams?

(897) How should shafts and slopes be sunk with respect to the dip?

(898) Describe the general features of the arrangements of landings, turnouts, and pit bottoms, in cases where arching is unnecessary.

(899) What should be the minimum size of slope pillars?

(900) What per cent. grade is used on landings?

(901) State in what direction, relative to the dip, pillars should be formed to be strongest.

(902) Why is pillar drawing delayed where the coal is soft?

(903) What must be carefully considered before the drawing of pillars is begun?

(904) Define (*a*) creep, (*b*) thrust.

(905) How would you stop a creep where it is gradually coming upon a section of the mine?

(906) What considerations are made in determining the size of pillars in the main workings?

(907) What conditions fix the size of the pillars relative to the breasts or rooms?

(908) When are rooms turned off both butt entries, and when are they turned off but one of the pair of butt entries?

(909) Which case in the last question requires the least amount of entry-driving?

(910) By what method would you work a 6-foot seam of coal which is 800 feet deep, has a soft bottom, gives off considerable gas, and readily disintegrates under atmospheric agencies? Give your reasons.

(911) What are barrier pillars?

(912) How is the track arranged in a breast pitching from 10° to 18°?

(913) At what pitches is sheet iron laid in the breasts of an anthracite seam?

(914) Describe two methods of constructing manways up the sides of the breasts.

(915) What is meant by "working on battery"?

(916) State the advantages of drawing off the surplus coal in a breast by a center chute.

(917) Why are the gangways in thick, pitching seams sometimes driven near the roof?

(918) In pitching seams, what danger is there in turning off the rooms the full width from the heading or airway?

(919) How is this risk avoided?

(920) When the chutes leading to the breasts pass under

the airway, what is done to restore ventilation to the rest of the breasts in case the manway is closed by a cave-in ?

(921) What are check batteries ?

(922) What is "rock-chute mining," and what are the undetermined points in connection with it ?

(923) Explain how several contiguous seams can be worked by tunneling horizontally through the intervening strata.

(924) What is a "back breast," and what does it accomplish ?

(925) Explain a method of robbing or drawing pillars in thick, pitching, anthracite seams.

(926) In approaching abandoned workings supposed to be filled with gas or water, what precautionary measures are necessary ?

(927) What determines whether or not twin seams should be worked separately ?

(928) Why are chutes not more frequently used in bituminous mines ?

(929) Explain fully how you would open up a breast in a seam 30 feet thick, of a soft, gaseous nature, and having a pitch of 60°.

(930) What direction should the productive entries have in general, with respect to the face cleats, and why ?

(931) How would you set a post in a seam pitching 36° ? Give the principle involved.

(932) When is it advisable to set props with their thick ends up ?

(933) How is mopping of props prevented when the bottom heaves ?

(934) What is done to cause uniformity of weight upon the props ?

(935) How are short curves and crooks avoided in driving headings ?

(936) What objections are there in keeping the grade uniform by following the strike of the seam ?

(937) What are the usual dimensions of headings, or gangways, in the different regions ?

(938) Upon what does the method of timbering a level largely depend ?

(939) How would you provide for sufficient height for a level in a seam 4 feet thick and pitching 30°, the roof being hard and the bottom moderately soft ? Show method of timbering.

(940) Show by sketch how you would timber a gangway through a thick seam of frail coal, where the roof is bad.

(941) Give three methods of strengthening a set of timbers so that it will more effectively resist lateral pressure.

(942) State the advantages of both the narrow and wide gauge roads.

(943) What size of T steel rails are used where the loads are heavy and high speeds are necessary ?

(944) How are roads arranged on grades over which the cars are run by brake or sprag ?

(945) What is the cause of the ties being knocked diagonally across the road by the mules while pulling the cars ?

(946) What would be a suitable switch to lay in a room turned off the main haulway ?

(947) Under what conditions are spring-latches used ?

(948) What essential difference should be made in laying a switch to the rise and one to the dip ?

(949) Show by sketch how you would make a switch in which tongues and frog, or cross-latch, can be dispensed with.

(950) How are crossings made, where high speeds are required on one road ?

(951) What should be the aim in arranging tracks in slopes ?

(952) When a slope has a very steep pitch, how is the coal hoisted?

(953) What disadvantage is likely to occur when caging is done from both sides of the shaft?

(954) What limits the use of iron plates in the operation of caging?

(955) If a heading is driven on the strike of the seam towards abandoned workings filled with water and located about 20 feet on the pitch, above the approaching heading, how should bore-holes be driven?

(956) What should be the minimum thickness of a barrier pillar between two anthracite collieries, when the seam is 15 feet thick and the workings are 400 feet vertically below the drainage level?

(957) What should be the minimum thickness of a barrier pillar between two bituminous mines when the seam is 6 feet thick, of average hardness, and the workings are 300 feet vertically below the drainage level?

(958) Describe the method of constructing a timber dam to divert the flow of water under small heads.

(959) What, according to formula, should be the thickness of a cylindrical wooden dam with a radius of curvature of 30 feet, to resist a maximum water head of 200 feet?

Ans. 7 ft.

(960) According to formula what should be the thickness of a cylindrical brick dam to close an opening 7 feet high, after trimming, and to resist a maximum water-head of 250 feet? Ans. 9 ft.

(961) What should be the thickness of a spherical brick dam to close an opening 8 feet high and 8 feet wide, after trimming, to resist a maximum water-head of 300 feet?

Ans. 6 ft. 4 in.

(962) What is the use of puddled clay in the construction of dams?

(963) What should be used as mortar in the construction of brick or masonry dams?

METHODS OF WORKING COAL MINES.

(PART 2.)

(964) State conditions under which the longwall methods of working a seam of coal are alone applicable.

(965) Why are seams situated at shallow depths frequently worked by longwall?

(966) Explain how you would work a flat seam of coal which is $2\frac{1}{2}$ feet thick and has a following stone from 16 to 20 inches thick. Give sketch showing the same.

(967) What is meant by working (*a*) *on the faces?* (*b*) *on the butts* or *ends?* (*c*) *long horn?* (*d*) *short horn?*

(968) In what way does a skilful miner take advantage of the weighting action upon the coal while he is mining or bearing in?

(969) What conditions other than natural are essential for successful longwall?

(970) Why is it necessary to form sufficient length of working face before regular working begins?

(971) How are contorted and highly inclined seams approached and opened out?

(972) State the conditions determining the distance between roadways leading to the working face.

(973) Describe a method of longwall in which the mine cars are not taken to the working face.

(974) State two methods of protecting the alinement of shafts in longwall workings.

(975) When the crushing action of the roof is unavoidably great, how should the working face advance with reference to the cleats?

(976) Where should the mining or bearing in be done in a seam of coal, and what should be the dimensions of the same?

(977) What danger is there in attempting to support too great a width of roof along the working face?

(978) Where the line of working face has considerable pitch, how is the face proportioned for the convenience of the miners?

(979) How are levels and temporary haulways laid out?

(980) How is the coal taken to the roadheads where the mine car is not taken along the working face?

(981) Where is a weak roof most likely to break, and how can it be prevented from breaking in that particular place?

(982) When the roof has a tendency to slip down hill, what points must be considered in order that the packwalls will not be destroyed?

(983) When is it necessary to consider the strata above that immediately overlying the coal?

(984) What determines the distance between the working face and the gob?

(985) How are pillars or chocks constructed in pitching seams?

(986) What determines the distance between levels which cut off the roadways leading to the working face?

(987) What is the principal point considered by miners while working a longwall face?

(988) Upon what does the degree to which the coal will be fractured along the working face depend?

(989) How is a skilful miner able to produce more lump coal than an unskilful one?

(990) How are the steps arranged at the face where pairs of roads are used for inclines?

(991) What is done where thick seams are worked by longwall?

(992) Where is the shearing usually made?

(993) When the roadways leading to the face are on the full rise, how is the coal delivered to the levels?

(994) Where the seam is pitching, how is the weight on the high side packwalls made to act vertically or nearly so?

(995) In what direction should the working face advance relative to the cleats, in order to obtain coal at a minimum cost?

(996) What in longwall takes the place of powder in loosening the coal?

(997) From what sources is material for stowage and packwalls obtained?

(998) What are the objections to stepped faces?

(999) What order is maintained in setting props along the working face?

(1000) Why is it necessary to take a certain portion of coal from the low side of a level and then tightly pack the space thus made?

(1001) What effect has gas on the working of coal?

(1002) Give the principal difficulties encountered in working pitching seams by longwall.

(1003) What points must be carefully considered while working contiguous seams?

(1004) What is the principal object in removing the chocks and props from the gob?

(1005) What is the direction of the face cleats with reference to the line of maximum dip?

(1006) What special advantages are there in favor of "longwall retreating" where conditions are such that "longwall advancing" can be used?

(1007) Upon what does the amount of settlement of the roof depend?

(1008) Explain how you would work three contiguous seams separated one from the other by from 4 to 6 feet of

strata and each about 4 feet thick. The seams outcrop on the mountain side and dip inwards from 10° to 20°.

(1009) How is the weight upon the working face properly regulated?

(1010) What conditions justify the adoption of a system of longwall in which the roadways are built temporarily or to last but a short time?

(1011) How is a gaseous seam made harder and tougher to work?

(1012) What advantages are obtained when the working face and roadways cross the pitch?

(1013) What are the principal points to be considered in longwall workings?

(1014) Explain the usual process of drawing timber.

(1015) When the longwall working is started from the shaft pillar, what precaution must be taken?

(1016) When are temporary wooden chocks built in the gob?

(1017) How is the height of the roads maintained in thin seams?

(1018) How is the stability of the packwalls on the rise side of levels in thick seams frequently accomplished?

(1019) Why are longwall systems of mining becoming more general in the United States?

(1020) In what two ways is the operation of mining or bearing in made unusually difficult?

(1021) What is the most economical method of delivering coal to the levels?

(1022) State where "blind pits" are used.

(1023) What should be the relative locations of the upcast and downcast shafts?

(1024) Why is creep less liable to occur in longwall than in the pillar and chamber methods?

(1025) Upon what does the order of working contiguous seams depend?

(1026) When are permanent doors put in, and what is previously done to direct the air to the face?

(1027) When is a slight heaving of the bottom at the face an advantage?

(1028) When props can not be recovered with safety for use again, how should they be destroyed?

(1029) What advantage is gained by combining longwall advancing and longwall retreating?

(1030) How may a great deal of the preliminary or narrow work in longwall retreating be delayed until considerable working face is formed?

(1031) In what case does timber drawing require special care?

(1032) Which system of working coal mines affords the best conditions for ventilation, and why?

(1033) If no building is more than 96 feet from the center of a shaft whose circular pillar is found to be 135 yards in diameter, what is the probable depth of the shaft?

Ans. 426 feet.

MECHANICS.

(PART 1.)

(1034) (*a*) What is a molecule? (*b*) What is an atom?

(1035) If a body has an average velocity of 40 feet per second, how far will it travel in 14 minutes?

Ans. $6\frac{4}{11}$ miles.

(1036) Show how to represent a force by a line.

(1037) In Fig. 603, let the distance $F c$ be 21 inches and $F b$ $3\frac{1}{2}$ inches; what weight will a force of 85 lb. applied at P raise?

Ans. 510 lb.

(1038) What must be the speed of the driver pulley, in order that the driven may make 80 R. P. M. and be 28 inches in diameter, the diameter of the driver being 21 inches?

Ans. $106\frac{2}{3}$ R. P. M.

(1039) The number of teeth in a spur-gear is 50, and the pitch is $1\frac{1}{2}$ inches; (*a*) what is the pitch diameter? (*b*) What is the outside diameter?

Ans. { (*a*) 23.87". (*b*) 24.77".

(1040) The driving gear has 45 teeth and the driven 180; if the driver makes 212 R. P. M., how many R. P. M. will the driven make?

Ans. 53 R. P. M.

(1041) What pressure can be exerted by a force of 24 pounds on a half-inch screw which has 13 threads per inch, the distance from the center of the screw to the point on the handle where the force is applied being 11 inches?

Ans. 21,563.94 lb.

(1042) A ball weighing 5 pounds revolves in a circle whose radius is 32 inches, at the rate of 350 R. P. M.; what is the pull on the support caused by the ball?

Ans. $555\frac{1}{3}$ lb.

§ 16

(1043) A body weighing 2 pounds has a velocity of 600 feet per second; what is its kinetic energy?

Ans. 11,194 ft.-lb.

(1044) What should be the width of a double leather belt to transmit 150 horsepower, when the belt has a velocity of 3,000 feet per minute, and has 7 feet of its length in contact with the smaller pulley, whose diameter is 63 inches? Give width to nearest half inch. Ans. 29.5 in.

(1045) (*a*) What are the three states of matter? (*b*) Name some of the general properties of matter; (*c*) some of the specific properties.

(1046) If a man could run a mile at the average rate of 100 yards in 12 seconds, how long would it take him?

Ans. 3 min. 31.2 sec.

(1047) What is meant by *center of gravity?*

(1048) (*a*) Why is crowning usually given to the face of a pulley? (*b*) Why should high-speed pulleys be balanced?

(1049) At what speed must the engine run when the diameter of the band-wheel is 13 feet and of the main pulley 91 inches, if the speed of the main shaft is to be 108 R. P. M.? Ans. 63 R. P. M.

(1050) The pitch of a gear is 2½ inches, and the number of teeth is 192; what is the pitch diameter?

Ans. 152.79 in.

(1051) How many revolutions per minute must the driving gear make if it has 18 teeth, and the driven has 81 teeth and makes 80 R. P. M.? Ans. 360 R. P. M.

(1052) The nuts on a cylinder-head are tightened by means of a wrench 26 inches long. The threads in the nuts are 8 to the inch, and the efficiency of the screw is 40%. What pressure will the nut exert against the head when a force of 60 pounds is applied to the end of the wrench?

Ans. 31,365.7 lb.

(1053) What do you understand by *specific gravity?*

(1054) If the center of gravity of a section of an engine fly-wheel rim is 6 feet 1¾ inches from the center of the

shaft, and the weight of the rim is 13,000 pounds, what is its kinetic energy when making 150 R. P. M.?

Ans. 1,883,661.7 ft.-lb.

(1055) What should be the width of a single leather belt to transmit $2\frac{1}{2}$ horsepower when the belt has a velocity of 2,000 feet per minute? The diameter of the smaller pulley is 14 inches, and the belt has 18 inches of its length in contact with it. Ans. $1\frac{1}{8}$ inch.

(1056) (*a*) What is meant by inertia? (*b*) by weight? (*c*) How is weight measured?

(1057) The speed of a certain belt is 3,000 feet per minute; if it drives a 48-inch pulley, how long will it take the pulley to make 100 revolutions? Ans. 25.13 sec., nearly.

(1058) Find the point of suspension of a rectangular cast-iron lever 4 feet 6 inches long, 2 inches deep, and $\frac{3}{4}$ inch thick, having weights 47 and 71 pounds hung from each end, in order that there may be equilibrium. Take the weight of a cubic inch of cast iron as .261 pound.

$$\text{Ans.} \begin{cases} \text{Short arm} = 22.342 \text{ in.} \\ \text{Long arm} = 31.658 \text{ in.} \end{cases}$$

(1059) When two pulleys are used to transmit power, which is called the driven and which the driver?

(1060) The driver is 2 feet in diameter and the driven is 32 inches in diameter; if the driven makes 63 R. P. M., how many R. P. M. must the driver make? Ans. 84 R. P. M.

(1061) A certain gear has a pitch of $1\frac{1}{8}$ inches, and its pitch diameter is 11.48 inches; how many teeth has the gear? Ans. 32 teeth.

(1062) A fly-ball governor is designed to run at 88 R. P. M. The speed of the engine is 200 R. P. M. The diameter of the governor-pulley is 8 inches; the number of teeth in the bevel-gear which it turns, 44, and the number of teeth in the other bevel-gear, 75. What must be the diameter of the pulley on the crank-shaft which drives the governor-belt? Ans. 6 in.

(1063) A bookbinder has a press, the screw of which has

4 threads to the inch. It is worked by a lever 15 inches long, to which is applied a force of 25 pounds; (*a*) what will be the pressure if the loss by friction is 5,000 pounds? (*b*) What would be the theoretical pressure?

Ans. { (*a*) 4,424.8 lb.
(*b*) 9,424.8 lb.

(1064) A cubic foot of a certain kind of wood weighs 51 pounds; what is its specific gravity? Ans. .816.

(1065) The piston of an engine weighs 325 pounds, including the piston-rod; what is its kinetic energy when moving at the rate of 660 feet per minute?

Ans. 611.4 ft.-lb., nearly.

(1066) What horsepower can be safely transmitted by a gear whose pitch is 1 inch, a point on the pitch-circle having a velocity of 1,200 feet per minute? Ans. 12 H. P.

(1067) (*a*) What is motion? (*b*) velocity? (*c*) rest? (*d*) Can a body be in motion with respect to one object and at rest with respect to another? Explain fully.

(1068) (*a*) What is force? (*b*) Name several kinds of forces.

(1069) Find by measurement the center of gravity of a triangle whose sides are 4 inches, 5 inches, and 6 inches long. Ans. $1\frac{3}{32}$ inches from 6-inch side.

(1070) The driving pulley makes 40 R. P. M.; the driven makes 60 R. P. M., and is 36 inches in diameter. What is the diameter of the driver? Ans. 54 inches.

(1071) The diameter of the band-wheel of an engine is 12 feet; of the main pulley, 8 feet; of a driving pulley on the main shaft, 20 inches; of the driven pulley on the counter-shaft, 6 inches; of the driver on the countershaft, 6 inches, and of the driven on an emery-wheel spindle, 4 inches. If the engine makes 80 R. P. M., (*a*) what is the speed of the main shaft? (*b*) of the countershaft? (*c*) of the emery-wheel?

Ans. { (*a*) 120 R. P. M.
(*b*) 400 R. P. M.
(*c*) 600 R. P. M.

(1072) The pitch diameter of a gear is 34.15 inches; if the pitch is $1\frac{3}{8}$ inches, how many teeth has the gear?

Ans. 78 teeth.

(1073) In order to raise a weight, a combination of a fixed and movable pulley is used. If a force of 225 pounds be applied to the free end of the rope, what load will it raise?

Ans. 450 lb.

(1074) If the power moves through a distance of 5 feet 6 inches, while the weight is moving 6 inches, (*a*) what is the velocity ratio of the machine? (*b*) What weight would a force of 5 pounds applied to the power-arm raise?

Ans. $\begin{cases} (a) & 11. \\ (b) & 55 \text{ lb.} \end{cases}$

(1075) In the last example, if the efficiency was 65%, what weight could the machine raise? Ans. 35.75 lb.

(1076) How many cubic inches of platinum will it take to weigh 10 pounds? Ans. 12.86 cu. in., nearly.

(1077) (*a*) For what are belts used? (*b*) What is a single belt? (*c*) a double belt?

(1078) What horsepower can be safely transmitted by a gear whose pitch is 1.57 inches, pitch diameter is 30 inches, and which makes 100 revolutions per minute?

Ans. 19.36 H. P.

(1079) (*a*) What is uniform motion? (*b*) What is variable motion? (*c*) If a body moves 10 feet the first second, 12 feet the second second, 15 feet the third second, etc., is its motion uniform or variable, and why?

(1080) What three conditions are required to be known in order to compare forces?

(1081) A steel rod $\frac{3}{8}$ inch in diameter has on one end a cast-iron spherical ball 5 inches in diameter; if the length of the rod is 40 inches between the ball and the end, where is the center of gravity?

SUGGESTION.—First calculate the weights of the ball and rod by the aid of the specific gravity tables.

Ans. 6.427 in. from the center of the ball.

(1082) The driving pulley makes 240 R. P. M. and the driven pulley 180 R. P. M.; if the diameter of the driven pulley is 30 inches, what is the diameter of the driver?

Ans. $22\frac{1}{2}$ inches.

(1083) In a train of gears used to raise a weight of 6,000 pounds in a manner similar to that shown in Fig. 612, the diameters of the drivers and belt pulley are 18 inches, 12 inches, 15 inches, and 12 inches, and of the pinions and drum, 6 inches, 5 inches, 8 inches, and 3 inches. What force must be applied to the belt to raise the weight, if 20% of the total force is lost through friction? Ans. $138\frac{8}{9}$ lb.

(1084) The pitch diameter of a gear is 24.16 inches, and the number of teeth is 38; what is the pitch?

Ans. 1.9974 in.

(1085) It is required to raise a load of 1,890 pounds by means of a block and tackle which has four fixed and four movable pulleys; what force is required to be applied to the free end of the rope? Ans. $236\frac{1}{4}$ lb.

(1086) In a block and tackle, the theoretical power necessary to raise a weight of 1,000 pounds is 50 pounds; (*a*) what is the velocity ratio? (*b*) If the actual power necessary to raise the load is 95 pounds, what is the efficiency?

Ans. $\begin{cases} (a) & 20. \\ (b) & 52.63\%. \end{cases}$

(1087) A piece of lead is $\frac{1}{2}$ inch in diameter and 10 inches long; how much does it weigh? Ans. 12.91 oz.

(1088) If the distance between the centers of the crank-shaft and main shaft is 38 feet, and the diameters of the band-wheel and main pulley are 11 feet and 7 feet respectively, what must be the length of the main belt?

Ans. 105 ft. 3 in.

(1089) The entire solar system is moving through space at the rate of 18 miles per second; (*a*) what is its velocity in miles per hour? (*b*) How far will it go in one day?

Ans. $\begin{cases} (a) & 64{,}800 \text{ mi. per hr.} \\ (b) & 1{,}555{,}200 \text{ mi.} \end{cases}$

(1090) (*a*) What is the path of a body? (*b*) What line do we measure when we wish to find the distance a body has traveled?

(1091) (*a*) How are forces measured? (*b*) What kind of an effect do forces always tend to produce?

(1092) It is required to raise a weight of 1,500 pounds by means of a lever like that shown in Fig. 596. The length of the lever is 4 feet, and the distance from the fulcrum to the weight is 4 inches; what force will it be necessary to apply? Ans. $136\frac{4}{11}$ lb.

(1093) Had the lever in the above example been like that shown in Fig. 597, what force would have been required?
Ans. 125 lb.

(1094) The band-wheel of an engine is 10 feet in diameter; what must be the diameter of the pulley on the main shaft in order to make 110 R. P. M., if the band-wheel makes 88 R. P. M.? Ans. 8 ft.

(1095) (*a*) What is a spur-gear? (*b*) a miter-gear? (*c*) a bevel-gear?

(1096) The pitch diameter of a gear is 36.56 inches, and the number of teeth is 42; what is the pitch?
Ans. 2.7347 in.

(1097) The length of an inclined plane is 400 feet, and the height is 45 feet. What force acting parallel to the plane will be required to pull up the plane a weight of 4,000 pounds? Ans. 450 lb.

(1098) (*a*) What is meant by the velocity ratio of a machine? (*b*) by efficiency?

(1099) If a coil of brass wire weighs 10 pounds, and the diameter of the wire is $\frac{1}{16}$ inch, how long is the wire?
Ans. 896 ft., nearly.

(1100) The diameters of two pulleys are 14 inches and 18 inches, and the distance between their centers is 14 feet; what must be the length of a belt to drive these pulleys?
Ans. 32 ft. 4 in.

(1101) A velocity of 30 miles per hour corresponds to how many feet per second? Ans. 44 ft. per sec.

(1102) The stroke of a steam-engine is 28 inches, and it makes 1,500 strokes in 6 minutes; what is the velocity of the piston in feet per second? Ans. $9\frac{13}{18}$ ft. per sec.

(1103) State Newton's three laws of motion.

(1104) A pulley on the main shaft is 40 inches in diameter, and makes 120 R. P. M. What must be the diameter of a pulley on the countershaft that is to make 160 R. P. M.? Ans. 30 in.

(1105) (*a*) What is a rack? (*b*) a worm-wheel? (*c*) a worm?

(1106) (*a*) What distinguishes epicycloidal teeth from the involute teeth? (*b*) Name two advantages which the latter possess over the former.

(1107) An inclined plane has a length of 1,200 feet and a height of 125 feet. It is required to pull a load of 50,000 pounds up this plane. A block and tackle having 6 fixed and 6 movable pulleys is stationed at the top of the plane, and the weight end of the rope is attached to the load. If the rope which connects the block to the load is parallel to the plane, what force will it be necessary to exert on the free end of the rope to pull up the load, no allowance being made for friction? Ans. 434 lb.

(1108) (*a*) What do you understand by centrifugal force? (*b*) by centripetal force?

(1109) Define (*a*) work; (*b*) horsepower; (*c*) kinetic energy; (*d*) potential energy.

(1110) Two pulleys have diameters of 8 inches and 20 inches; the distance between their centers being 19 ft. 3 inches, what must be the length of a belt to drive them? Ans. 42 ft. $3\frac{1}{2}$ in.

(1111) Two bodies, starting from the same point, move in opposite directions, one at the rate of 11 feet per second and the other 15 miles per hour. (*a*) What will be the distance

between them at the end of 8 minutes? (*b*) How long before they will be 825 feet apart?

Ans. $\begin{cases} (a) \text{ 3 miles.} \\ (b) \text{ 25 seconds.} \end{cases}$

(1112) A railroad-train runs 2 miles in 2 minutes and 10 seconds; what is its average velocity in feet per second?

Ans. 81.23 ft. per sec.

(1113) Why is it difficult to jump from a rowboat into the water?

(1114) A compound lever, similar to the one shown in Fig. 602, is required to lift a weight of 1,250 pounds. The lengths of the power-arms $P F$ are 30 inches, 20 inches, 10 inches, and 15 inches, respectively, and the lengths of the weight-arms $W F$ are 6 inches, 5 inches, 4 inches, and 7 inches; what force will be required? Ans. 11⅔ lb.

(1115) The diameter of the driving pulley is 20 inches and that of the driven is 16 inches. If the driver makes 150 R. P. M., how many will the driven make?

Ans. 187½ R. P. M.

(1116) How is the diameter of a gear measured?

(1117) The driving gear makes 100 R. P. M. and the driven 40 R. P. M.; if the driven has 60 teeth, how many has the driver? Ans. 24.

(1118) The base of an inclined plane is 80 feet long, and the height of the plane is 50 feet; what force exerted parallel to the base will raise a load of 750 pounds? Ans. 468¾ lb.

(1119) What is the centrifugal force of the counterweight of a steam-engine, the counterweight weighing 128 pounds, and its center of gravity being 8⅞ inches from the center of the shaft? The crank makes 180 R. P. M.

Ans. 1,028.16 lb.

(1120) How much work can be done by 20 cubic feet of water falling from a height of 50 feet? Ans. 62,500 ft.-lb.

(1121) What horsepower can be transmitted by a single leather belt 5 inches wide, which runs at the rate of 1,960 ft.

per min.? The diameter of the smaller pulley is 15 inches, and the length of the arc of contact is 21 inches.

Ans. 11.4 H. P., nearly.

(1122) It is required to raise a weight of 18,000 pounds by means of a screw having 3 threads per inch; if the length of the handle is 15 inches, and there is a loss of 10,000 pounds, due to friction, etc., what force will it be necessary to apply to the handle? Ans. 99 lb., nearly.

(1123) The fly-wheel of an engine is 9 feet in diameter (outside); if the fly-wheel makes 100 R. P. M., how many miles will a point on the rim travel in 1¼ hours?

Ans. 40.16¼ miles.

(1124) Suppose that an air-gun can throw a ball with a velocity of 100 feet per second, and that a man standing on a railroad-train, which is moving at the rate of 100 feet per second, were to fire the gun in a direction exactly opposite to that in which the train is moving, what would become of the ball? Why?

(1125) If the distance between the center line of the handle and the axis of the drum shown in Fig. 604 is 14½ inches, and the diameter of the drum is 5 inches, what load will a force of 30 pounds exerted on the handle raise?

Ans. 174 lb.

(1126) A pulley on the main shaft is 42 inches in diameter, and makes 108 R. P. M. What will be the speed of the countershaft if the driven pulley is 36 inches in diameter? Ans. 126 R. P. M.

(1127) (*a*) What is the pitch-circle? (*b*) the pitch of a gear?

(1128) The driving gear makes 360 R. P. M., and the driven makes 170 R. P. M.; if the driver has 34 teeth, how many teeth has the driven? Ans. 72 teeth.

(1129) Name some particular use in the engine-room or shop to which you have seen the inclined plane put.

(1130) Assuming the average pressure upon the piston of a steam-engine to be 41.38 pounds per square inch, what

is the horsepower? The diameter of the piston is 10 inches, the stroke 16 inches, and the number of strokes per minute 450. Ans. 59.091 H. P., nearly.

(1131) What horsepower can be transmitted by a 20-inch double leather belt which has a velocity of 2,800 feet per minute? The diameter of the smaller pulley is 4 feet, and the belt has 5 feet 9 inches of its length in contact with it. Ans. 99.41 H. P.

MECHANICS.

(PART 2.)

(1132) What is meant by the expression, *the resultant of several forces?*

(1133) If in Fig. 631 the tension in the rope is 3¾ tons, and the angle at *d* between the directions of the two parts of the rope is 30°, what is the total load on the shaft of the head-wheel?

(1134) (*a*) What do you understand by tensile strength of a material? (*b*) by working stress?

(1135) A close-link wrought-iron chain is made from ⅜-inch iron; what is the greatest safe load that it will carry? Ans. 1,687.5 lb.

(1136) What is the allowable working load for a steel-wire rope 5¼ inches in circumference? Ans. 27,562.5 lb.

(1137) What steady force is required to shear a steel crank-pin which is 6 inches in diameter? Ans. 1,696,464 lb.

(1138) If a line 5 inches long represents a force of 20 pounds, (*a*) how long must the line be to represent a force of 1 pound? (*b*) of 6¼ lb.?

(1139) (*a*) What is cold-rolled shafting? (*b*) bright shafting? (*c*) black shafting?

(1140) Find the resultant of the forces acting in Fig. 805—all acting towards the same point.

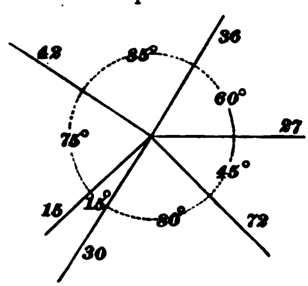

FIG. 805.

(1141) The smallest section of a connecting-rod is 3.5 square inches; what is the unit stress when subjected to a tensile stress of 12,400 pounds? Ans. 3,543 lb. per sq. in., nearly.

(1142) What load may be safely carried by a hemp rope 4 inches in circumference? Ans. 1,600 lb.

(1143) What load can be safely sustained by a round wooden pillar, 8 inches in diameter and 10 feet long, having both ends flat? 13¼ tons.

(1144) What are the components of a force?

(1145) What should be the least diameter of a wrought-iron bolt that is to resist a sudden pull of 12,000 pounds?

Ans. 1.74 + in.

(1146) A steel-wire rope is 4¾ inches in circumference; what load will it safely sustain? Ans. 22,562.5 lb.

(1147) A white-pine beam supported at both ends has a rectangular cross-section 8 inches wide by 10 inches deep; if the beam is 28 feet long, what total uniform load will it support in safety? Ans. 6,857¼ lb.

(1148) What horsepower can a 10-inch wrought-iron crank-shaft transmit when running at 200 revolutions per minute? Ans. 2,857¼.

(1149) If a body be acted upon by two equal forces, one due east and the other due south, in what direction will the body move? What is the direction of the resultant of the two forces?

(1150) What should be the least area of one of the 14 wrought-iron cylinder-head stud-bolts, if the diameter of the cylinder is 19 inches, and the greatest steam-pressure is 180 pounds per square inch? Assume that the studs are subjected to shocks. Ans. .729 sq. in.

(1151) What should be the circumference of a hemp rope to safely sustain a load of 4,200 pounds? Ans. 6½ in

(1152) Regarding the connecting-rod of a steam-engine as a pillar with two round ends, what is the greatest force that may be exerted on the cross-head if the connecting-rod is made of wrought iron, is 10 feet long, and has a rectangular cross-section 6 inches by 2½ inches? Ans. 35,489 lb.

(1153) If you were to order 2½-inch bright turned shafting, what size would you expect to get?

(1154) A peg in the wall is pulled by two strings, one with a force of 21 pounds, at an angle to the vertical of 45°, and the other with a force of 28 pounds, at an angle of 60°; what is the value and direction of the resultant when the forces are on opposite sides of the vertical line? Use the method of parallelogram of forces. Ans. 30.34 lb.

(1155) A force of 87 pounds acts at an angle of 23° to the horizontal; what are its horizontal and vertical components? Find, first, by the method of triangle of forces, and, second, by trigonometry. Ans. $\begin{cases} 33.994 \text{ lb.} \\ 80.084 \text{ lb.} \end{cases}$

(1156) What is the greatest safe load that may be applied to a stud-link wrought-iron chain, if the diameter of the iron from which the link is made is $\frac{1}{2}$ inch? Ans. 4,500 lb.

(1157) It is desired to haul loads up to 14,000 pounds by means of an iron-wire rope; what should be its circumference? Ans. 4.83 in., nearly.

(1158) What is the greatest load that a bar of wrought iron 2 inches in diameter and 6 feet long can safely sustain in the middle? The bar is merely supported at its ends. Ans. 480 lb.

(1159) What must be the diameter of a cast-iron crank-shaft to transmit 1,000 horsepower at 80 revolutions per minute? Ans. 10.4 in.

(1160) Two forces act upon a body at a common point—one with a force of 75 pounds, and the other with a force of 40 pounds; if the angle between them is 60°, and both forces act towards the body, what is the value of the resultant? Solve by the method of triangle of forces and parallelogram of forces, and mark the direction of the resultant. Ans. 101.12 lb.

(1161) In the last example, if one force (the one of 75 pounds) acts away from the body, and the other towards it, what is the resultant? Solve by the method of triangle of forces and parallelogram of forces, and mark the direction of the resultant. Ans. 65 lb.

(1162) If two forces, of 27 pounds and 46 pounds

respectively, act in exactly opposite directions upon a body, what is the resultant?

(1163) A bar of steel having a cross-section of $1\frac{3}{4}$ inches by 3 inches is subjected to a tensile stress; if the stress is suddenly applied, what is the greatest load that it will safely carry? Ans. 31,500 lb.

(1164) A load of 2,400 pounds is to be raised by means of a hemp rope; what should be the circumference of the rope? Ans. 4.9 in.

(1165) Six forces act towards the center of gravity of a body at angles of 30°, 45°, 135°, 210°, 225°, and 300° with the horizontal. If the magnitudes of the forces are 75, 47, 61, 32, 53, and 98 pounds, respectively, what is the value of their resultant? Solve by method of polygon of forces. Ans. $45\frac{3}{4}$ lb.

(1166) In laying out an engine-plane, it was found necessary to lead the rope around two guiding-sheaves, as shown

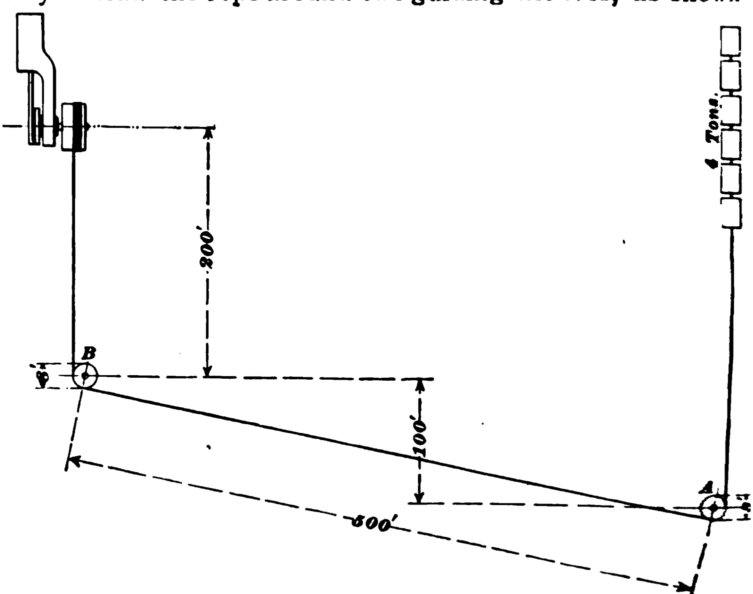

FIG. 806.

in Fig. 806. The portion of the rope between the car and the sheave A is parallel to the portion of the rope led from

the engine to the sheave B. The locations of the sheaves are found from the dimensions given. The resistance due to the cars and coal—that is, the tension in the rope—is 4 tons. What is the greatest pressure on the shaft of each sheave? Solve graphically by means of the parallelogram of forces.

Ans. $\begin{cases} \text{Pressure on sheave } A\text{, 12,400 lb., nearly.} \\ \text{Pressure on sheave } B\text{, 10,125 lb., nearly.} \end{cases}$

(1167) (*a*) What is a stress? (*b*) a strain? (*c*) a unit stress?

(1168) The links in a stud-link wrought-iron chain are made from iron $\frac{13}{16}$ inch in diameter; what is the greatest safe load that the chain can handle? Ans. 11,883 lb.

(1169) A steel-wire rope is used to haul cars up an inclined plane; the greatest stress in the rope is 8,000 pounds; what should its circumference be? Ans. 2.83 in.

(1170) What uniform load can be safely sustained by a steel beam 20 feet long, 2 inches wide, and 6 inches deep?

Ans. 4,608 lb.

(1171) A 4-inch steel shaft, with pulleys between bearings, is to transmit 80 horsepower; how many revolutions per minute must it make? Ans. 106¼ R. P. M.

(1172) (*a*) What is elasticity? (*b*) elastic limit? (*c*) What is meant by set?

(1173) What safe load may be carried by a close-link wrought-iron chain whose links are made from $\frac{5}{8}$-inch iron?

Ans. 4,687.5 lb.

(1174) What is the allowable working load for an iron-wire rope 6 inches in circumference? Ans. 21,600 lb.

(1175) What force is required to shear a wrought-iron strip 4 feet long and ½ inch thick? Ans. 960,000 lb.

(1176) A 7-inch wrought-iron crank-shaft is to transmit 200 horsepower; how many revolutions per minute must it make? Ans. 40.8 rev., nearly.

(1177) What force is required to punch a 1-inch hole through a wrought-iron plate $\frac{7}{16}$ inch thick? Ans. 54,978 lb.

(1178) What horsepower will a $1\frac{7}{8}$-inch wrought-iron

shaft transmit when running at 180 revolutions per minute? There are pulleys between bearings. Ans. 12.49 H. P.

(1179) A steam-cylinder is 44 inches in diameter, and sustains a steam-pressure of 100 pounds per square inch. The diameter of the cylinder-head studs is $1\frac{3}{8}$ inches, and the area at the bottom of the thread is 1.057 square inches. How many wrought-iron studs are required? Assume that the studs are subjected to shocks. Ans. 29 studs.

(1180) An iron-wire rope 4 inches in circumference is used for hoisting; what is the greatest load that the rope will sustain with safety? Ans. 9,600 lb.

(1181) A cast-iron rectangular cantilever beam, having a cross-section of $1\frac{1}{2}$ inches wide by $2\frac{1}{2}$ inches deep, is 4 feet 8 inches long; how great a weight will the beam sustain at its end? Ans. 201 lb., nearly.

(1182) What horsepower will a $2\frac{7}{16}$-inch steel shaft transmit when running at 120 revolutions per minute, there being pulleys between bearings? Ans. 20,445 H. P.

(1183) What safe steady load can be sustained by a $1\frac{1}{2}$-inch round wrought-iron bar, the load producing a tensile stress? Ans. 21,205.2 lb.

(1184) What load can a hemp rope 6 inches in circumference carry with safety? Ans. 3,600 lb.

(1185) What load will a hollow cast-iron pillar support with safety if the pillar is 20 feet long, outside diameter 14 inches, inside diameter $11\frac{1}{2}$ inches, and both ends are fixed? Ans. 219.24 tons.

(1186) What force is required to punch a hole $1\frac{1}{2}$ inches in diameter through a $\frac{3}{4}$-inch steel plate? Ans. 212,058 lb.

(1187) A weight of 325 pounds rests upon a smooth inclined plane, as shown in Fig. 636. If the angle of the plane is 15°, (*a*) what is the perpendicular pressure against it? (*b*) What force would it be necessary to exert parallel to the plane to keep it from sliding downwards, there being no friction? Solve by trigonometry, and also by the method of the triangle of forces.

Ans. $\begin{cases} (a) & 313.93 \text{ lb.} \\ (b) & 84.12 \text{ lb.} \end{cases}$

STEAM AND STEAM-BOILERS.

(1188) (*a*) What is heat? (*b*) Suppose a closed vessel containing air is placed in a furnace; describe the effect of the heat upon the molecules of the air. (*c*) If the vessel is so arranged that the air can not escape or expand, will the pressure of the air increase as it is heated? (*d*) Why?

(1189) (*a*) What is temperature? (*b*) Describe the thermometer. (*c*) Of what is temperature a measure?

(1190) A bar of iron weighing $2\frac{1}{2}$ pounds has a temperature of 460°. Does the bar contain more or less heat than 10 pounds of water at 60°?

(1191) (*a*) What are some of the effects of heat? (*b*) Give some practical illustrations of the expansion of bodies by heat.

(1192) (*a*) What is a B. T. U.? (*b*) What is latent heat? (*c*) What is sensible heat? (*d*) What is meant by the specific heat of a substance?

(1193) A pound of ice at 16° is heated until it finally is changed to steam at atmospheric pressure. (*a*) Describe the action of the heat upon the ice and water. (*b*) How many B. T. U. are required for the operation? (*c*) What part of the heat applied is sensible heat? (*d*) What part is latent heat?

(1194) (*a*) What is the mechanical equivalent of heat? (*b*) Give examples of heat changed to work, and *vice versa*. (*c*) How many foot-pounds of work are equivalent to $30\frac{1}{2}$ B. T. U.? Ans. (*c*) 23,729 ft.-lb.

(1195) Assuming 20% of the heat to be utilized, how

many heat-units per hour are required to run an engine developing 35 horsepower? Ans. 445,372.5 B. T. U.

(1196) In a power plant, the engine extracts 8% of the heat produced by the combustion of the coal. Assuming that the combustion of the coal produces 14,000 B. T. U. per pound, how many pounds of coal per H. P. per hour are used by the engine? Ans. 2.27 lb.

(1197) How many B. T. U. are required to raise the temperature of $22\frac{1}{2}$ pounds of sulphur from 44° to 68°?
Ans. 109.4 B. T. U.

(1198) (*a*) What is the latent heat of fusion of ice? (*b*) How many B. T. U. are required to melt a cake of ice weighing 11 pounds and having a temperature of 17°?
Ans. (*b*) 1,667.16 B. T. U.

(1199) How many B. T. U. are required to raise 6 pounds of superheated steam from 310° to 342°?
Ans. 92.256 B. T. U.

(1200) A ball of copper at 305°, weighing 18 pounds, and an iron rod at 278°, weighing 13 pounds, are plunged into a bath of water at 56°. If the water weighs 32 pounds, what will be its final temperature? Ans. 77.45°.

(1201) (*a*) How many B. T. U. are required to change a pound of water at 212° into steam at atmospheric pressure? (*b*) How many B. T. U. are required to change 8 pounds of water at 63° into steam at 212°? Ans. (*b*) 8,920 B. T. U.

(1202) How many B. T. U. are required to change 2.2 lb. of ice at 23° into steam at 212°? Ans. 2,847.98 B. T. U.

(1203) (*a*) What is saturated steam? (*b*) superheated steam? (*c*) In what way does saturated steam differ from a perfect gas?

(1204) (*a*) What are the essential features of the horizontal fire-box or locomotive-boiler? (*b*) of the water-tube boiler?

(1205) What is the difference between an externally fired flue-boiler and a return tubular boiler?

(1206) In a fire-box or locomotive-boiler, what method is employed to strengthen the furnace and the external portion of the boiler which surrounds the furnace?

(1207) Describe four different ways of setting boilers, and how provisions are made for their expansion and contraction.

(1208) How are boilers generally braced?

(1209) Do the flues and tubes used in boilers diminish their strength? Give reasons.

(1210) What is about the level at which the water should stand in a horizontal cylindrical boiler?

(1211) What are water-cocks? Why should they be mounted upon every boiler?

(1212) (*a*) What is air? (*b*) Does the nitrogen of the air tend to increase or diminish the temperature of combustion in a furnace? Why?

(1213) Can the combustion of fuels take place without the presence of oxygen?

(1214) When hydrogen is burned, what does it form with the oxygen of the air?

(1215) How much heat is generated by the combustion of the carbonic oxide gas, formed from one pound of carbon, to carbonic acid gas?

(1216) What is the total amount of heat required to convert a pound of water at 32° F. into steam at 400° F.; or, in other words, what is the total heat of evaporation of one pound of saturated steam of 400° F.? Ans. 1,203.4 B. T. U.

(1217) What is the total amount of heat required to convert a pound of water at 32° F. into steam at a gauge-pressure of 175 pounds per square inch; or, in other words, what is the total heat of evaporation of one pound of saturated steam at an absolute pressure of 189.7 pounds per square inch?

NOTE.—Find temperature first by formula **138.**

Ans. 1,198.6 B. T. U.

(1218) If we have 5 cubic feet of saturated steam in a cylinder at 60 pounds pressure above a vacuum, what will be its pressure after it has expanded to 2.5 times its original volume, assuming the expansion to follow Mariotte's law?

Ans. 9.3 pounds per square inch above the atmospheric pressure.

(1219) If 11 pounds of coal are burned per square foot of grate surface per hour in a furnace having a grate area of 13 square feet, how many B. T. U. will be generated in 5 hours, if the combustion of the coal is complete?

Ans. 10,105,095 B. T. U.

(1220) How much air would have to be supplied to promote the complete combustion of the coal in Question 1219, if the furnace is operated under a blast draft?

Ans. 10,010 lb.

(1221) What is the equivalent of the heat of combustion of the fuel in Question 1219, expressed in pounds of water evaporated from 62° F. and at 212° F.?

Ans. 9,059.05 lb. of water.

(1222) The pressure in a boiler is 3,600 pounds per square foot above a vacuum; what is the pressure in the boiler measured in pounds per square inch above the atmospheric pressure? Ans. 10.3 lb. per sq. in.

(1223) Does saturated steam contain the same amount of heat per unit of weight at all pressures?

(1224) If a vertical boiler were generating steam at a gauge-pressure of 152 pounds per square inch, what would be the temperature of the water in the boiler?

Ans. 371.62° F.

(1225) On placing a thermometer in a jet of steam issuing from a blow-off pipe, we find its temperature to be 232° F.; what is the pressure behind the steam?

Ans. 5.57 lb. per sq. in. gauge-pressure.

(1226) If a coal-mine having a shaft 296 feet deep has an output of 132 tons of coal per hour, how many of the British

Thermal Units of heat supplied to the hoisting-engines with the steam are consumed in raising this coal from the bottom of the shaft? Ans. 100,442.15 B. T. U. per hour.

(1227) By the combustion of fuel in the furnace of a boiler, the steam generated during a run of two hours absorbed 277,160 British Thermal Units of heat; if none of the heat had been lost in its transformation into work through the medium of the hoisting-engine to which it was supplied, how many foot-pounds of work per hour would the engine have done? Ans. 107,815,240 ft.-lb. per hr.

(1228) A water-tube boiler is built up of a series of 4-inch lap-welded tubes, which are expanded into cast-iron headers through accurately cut holes. The steam and water drums are 24 and 20 inches in diameter respectively, and are made of single-riveted steel boiler-plate $\frac{5}{16}$ of an inch thick. The mud-drum is made of cast iron, and is only 10 inches in diameter. What is the greatest safe boiler-pressure under which the boiler can be operated?

Ans. 216.25 pounds per square inch above atmospheric pressure.

(1229) A horizontal return tubular boiler has a water-heating surface of 1,620 square feet; what is the approximate horsepower of the boiler? Ans. $101\frac{1}{4}$ H.P.

(1230) A water-tube boiler has a total water-heating area of 3,025 square feet; what is the probable horsepower of the boiler? Ans. 275 H. P.

(1231) The sum of the cross-sectional areas of all the tubes of a 348-horsepower fire-box tubular boiler amounts to 12 square feet; what should be the height of a chimney for this boiler to produce the necessary amount of draft?

Ans. 111 ft.

(1232) Describe two methods of drying steam before it finally leaves the boiler.

(1233) What is the difference between a chimney and a

forced or blast draft? What advantage has the latter over the former?

(1234) What means are usually supplied to facilitate the cleaning of boilers?

(1235) Why are steam-gauges a necessary part of every boiler?

(1236) Why should the water in a boiler be prevented from getting low while the furnace is in full operation?

(1237) Why are internally fired boilers usually bricked in?

(1238) How is the masonry work about a boiler usually strengthened?

(1239) Where should firebrick be used when setting a boiler?

(1240) Describe three different kinds of grates with which you are familiar.

(1241) What is a steam-pipe? a feed-water pipe? a blow-off pipe?

(1242) What are safety-valves? Describe the principle upon which they are operated.

(1243) How far must a 54-pound weight be placed from the fulcrum of a safety-valve that has an area of 6 square inches and is 2 inches from its fulcrum, if the valve is to blow off at 81 pounds per square inch? Ans. 18 in.

(1244) The shell of a plain cylindrical boiler is 30 inches in diameter and 20 feet long, and is made of single-riveted wrought-iron boiler-plate $\frac{3}{8}$ of an inch thick; what is the greatest boiler-pressure under which it can be safely operated? Ans. 127.8 lb. per sq. in.

(1245) (*a*) What is meant by the horsepower of a boiler? (*b*) What is the standard horsepower?

(1246) (*a*) What is meant by the term *heating-surface*? (*b*) What portions of an ordinary vertical boiler are heating-surface?

(1247) If you were placed in charge of a flue-boiler 45 inches in diameter, made of $\frac{5}{16}$-inch double-riveted iron plates, would you consider it safe to carry 110 pounds pressure?

(1248) A vertical boiler is rated at 35 horsepower. (*a*) What is the probable grate-surface? (*b*) What is its probable heating-surface? (*c*) Under ordinary conditions, how much water per hour would this boiler evaporate, taking the temperature of the feed at 100° and the steam-pressure at 70 pounds?

STEAM-ENGINES.

(1249) Name the stationary parts of a plain slide-valve engine.

(1250) In an indicator-diagram, what is represented by the expansion-curve of steam ?

(1251) Between what points does the plain slide-valve pass the central position of its travel ?

(1252) What is the usual range of cut-off of the plain slide-valve ?

(1253) In Figs. 807, 808, 809, and 810 are given two sets of indicator-diagrams taken from the same engine when running under full load and no load, respectively. Determine from each diagram the steam-pressure in the cylinder of the engine at the point of cut-off. Also the pressure at the point of release and at the point of compression. What is the back-pressure in each case ?

(1254) What was the M. E. P. in the cylinder of the engine at the time the diagrams shown in Figs. 807 and 808 were taken ? Ans. 43.29 pounds per sq. in.

(1255) What was the M. E. P. in the cylinder of the engine at the time the diagrams shown in Figs. 809 and 810 were taken ? Ans. 14.96 pounds per sq. in.

(1256) The diagrams Figs. 807 and 808 were taken from an engine with a cylinder 15 inches in diameter, with 24-inch stroke, and making $87\frac{1}{2}$ rev. per minute. Using the M. E. P. found in Question 1254, find the indicated horse-power of the engine. Ans. I. H. P. = 81.14.

(1257) When working under no load, the engine of Question 1256 gives the diagrams shown in Figs. 809 and 810.

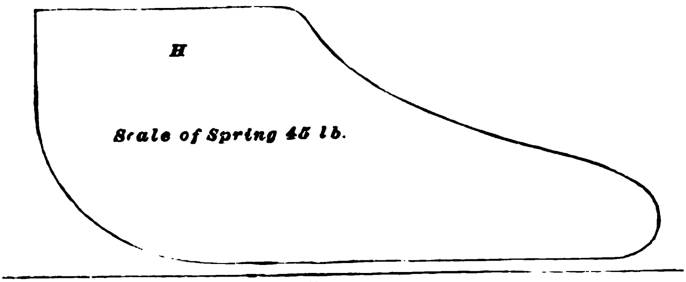

FIG. 807.

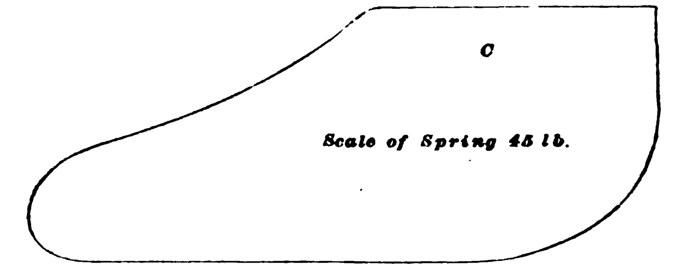

FIG. 808.

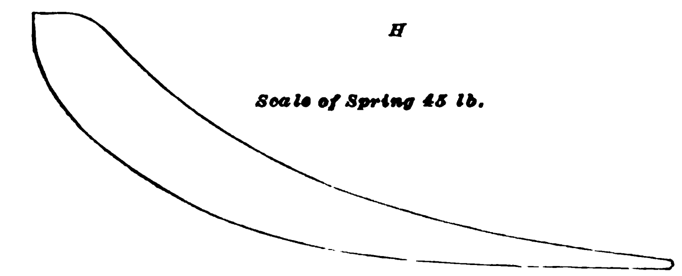

FIG. 809.

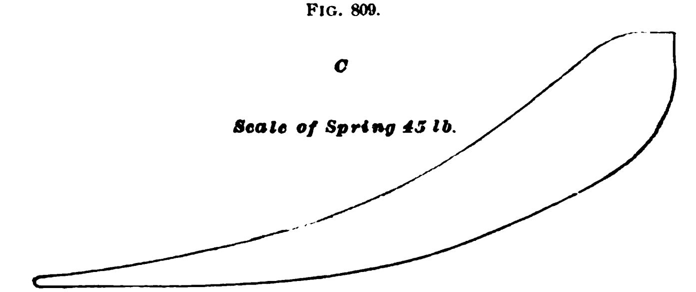

FIG. 810.

The M. E. P. is 14.96 lb. What is the indicated horsepower in this case ? Ans. I. H. P. = 28.04.

(1258) What is the actual horsepower and efficiency of the engine mentioned in Questions 1253 to 1257 ?

Ans. { Actual horsepower = 53.1.
Efficiency = 65.4 per cent.

(1259) What are the forces which, acting on the fly-balls of a pendulum-governor, cause them to move up and down as the speed of the engine varies ?

(1260) What is a triple-expansion engine ?

(1261) Name the parts of a plain slide-valve engine to which motion is imparted when the engine is running.

(1262) Why are engines supplied with fly-wheels ?

(1263) At the *point of release* of steam from the crank end of the cylinder, what is occurring in the head end of the cylinder ? .

(1264) What is the steam-lap of a plain slide-valve, and why is it given to the valve ?

(1265) Determine from the indicator-diagrams, Figs. 807, 808, and 809, 810, at what point in the stroke cut-off occurs.

(1266) Determine approximately the dimensions of a single-cylinder non-condensing engine to furnish 65 actual horsepower.

(1267) What is the difference between a duplex and a compound engine ?

(1268) What is a vertical or upright engine ?

(1269) What is the *stroke* of an engine, and to what is it equal ?

(1270) What is an eccentric, to what is it equivalent, and what duty does it perform ?

(1271) What is meant by the period of compression, and when does it occur ?

(1272) What is the effect of giving inside or exhaust lap to a plain slide-valve ?

(1273) What is the advantage of the Corliss valve-gear over the plain slide-valve?

(1274) Find the I. H. P. of an 18-in. × 24-in. engine whose mean effective pressure is 62.4 pounds per square inch, and which makes 175 revolutions per minute.

Ans. 336.825 I. H. P.

(1275) When an engine has two cranks, why are they placed at right angles to each other on the shaft?

(1276) What initial steam-pressure is generally used in compound and triple-expansion engines, and how many expansions of the steam are usually effected in each type?

(1277) What is meant by the *bore* of a cylinder?

(1278) When is steam called *live steam*, and in what form is energy stored in the live steam?

(1279) How is the resistance offered by the steam in the cylinder during the period of compression overcome?

(1280) (*a*) What are the "dead-center" positions of the crank and piston? (*b*) How many times is the crank on a dead-center during one revolution of the fly-wheel?

(1281) What is a steam-engine indicator, and how is it attached to the cylinder of a steam-engine?

(1282) Why do duplex, cross-compound, and triple-expansion engines usually run more smoothly than single-cylinder or tandem-compound engines?

(1283) What is the *counterbore* of a cylinder, and why is counterbore given to a cylinder?

(1284) What is meant by *back-pressure?*

(1285) What is meant by the period of release, and what point marks its end?

(1286) In what direction should the fly-wheel be rotated when determining the dead-center positions of the crank?

(1287) How many springs are there in an indicator, and what is the use of each?

(1288) If a condenser capable of producing a $\frac{5}{6}$ vacuum had been used in connection with the engine from which

the cards shown in Figs. 807, 808 and 809, 810 were taken, what would have been the effect upon the back-pressure line of the cards?

(1289) How are hoisting and tail-rope haulage-engines governed?

(1290) What is meant by *clearance* of a steam-cylinder?

(1291) How is motion imparted to the slide-valve?

(1292) During the period of expansion in the crank end of the cylinder, what occurs in the head end of the cylinder?

(1293) What does the compression-curve show?

(1294) In what direction should the fly-wheel be rotated when setting a plain slide-valve?

(1295) What is meant by a *40-pound*, a *20-pound*, or a *75-pound* indicator-spring?

(1296) What is the scale of an indicator-spring?

(1297) What is the advantage of using the condensed steam from a condenser, as boiler feed-water?

(1298) What outlet is provided in steam-cylinders for the discharge of water that may accumulate as the result of the condensation of steam?

(1299) What is the angle between the crank and eccentric?

(1300) If a valve has a slight lead, does the point of admission occur at the beginning or end of the stroke?

(1301) What conditions must be fulfilled in setting a plain slide-valve?

(1302) Why is it necessary to employ a reducing motion in connection with an indicator?

(1303) If a non-condensing engine is working under a boiler-pressure of 75 pounds per square inch, what is the approximate M. E. P. if the engine cuts off at $\frac{3}{10}$ stroke? at $\frac{1}{2}$ stroke?

Ans. 41.86 and 53.16 lb. per sq. in., respectively.

(1304) What is the principle that insures the action of steam-engine governors?

(1305) What is the difference between first and second motion hoisting-engines?

(1306) Why is a piston supplied with split rings?

(1307) What is meant by the *point of cut-off?*

(1308) If a valve has no lead, is the steam-port opened or closed when the crank is on its dead-center?

(1309) What is meant by a valve having *lead?*

(1310) An engine has a piston speed of 350 feet per minute, and makes 175 revolutions per minute; what is the length of the stroke? Ans. 12 inches.

(1311) Explain the relative duties of a governor and fly-wheel in effecting the regulation of the speed of the engine.

(1312) Explain the action of the compound and of the triple-expansion engine.

(1313) What are stuffing-boxes, and why are they a necessary part of every engine?

(1314) What is meant by the *atmospheric line?*

(1315) How do you determine the length of the stroke and point of cut-off of an engine?

(1316) It is desired to take an indicator-diagram 3 inches in length from an engine of which the length of the stroke is 12 inches and the effective length of the reducing-lever is 96 inches; what is the distance of the point on the lever below the center of the fulcrum at which the cord is to be attached? Ans. 24 inches.

(1317) An engine has a stroke of 48 inches, and makes 50 revolutions per minute; what is the piston speed?

Ans. 400 feet per minute.

(1318) What takes the place of the fly-wheel in hoisting and haulage engines, which have no fly-wheels?

(1319) What is the difference between a tandem and a cross-compound engine? What are the advantages of the tandem type? of the cross-compound type?

(1320) What is the *period of expansion*, and what points mark its beginning and end?

(1321) Between what points are the steam-ports fully open by the valve to the admission of live steam into the cylinder?

(1322) Find the I. H. P. developed by a 22-in. × 18-in. engine making 200 revolutions per minute. The M. E. P. is 43.4 lb. per sq. in. Ans. 300 I. H. P.

(1323) What is meant by the term *mean effective pressure?*

(1324) An engine has a piston speed of 750 feet per minute and a stroke of 60 inches; how many revolutions does the crank make per minute? Ans. 75.

(1325) What is the difference between an automatic and a throttling governor?

(1326) What are the advantages to be gained by compounding?

AIR AND AIR COMPRESSION.

(1327) What do you understand by tension of gases?

(1328) A cylinder filled with compressed air supports a column of mercury 4 feet high; (*a*) what is the tension of the air in pounds per square inch? (*b*) in atmospheres? Take the weight of a cubic inch of mercury in all cases as .49 pound.

Ans. $\begin{cases} (a) & 23.52 \text{ lb.} \\ (b) & 1.6 \text{ atmos.} \end{cases}$

(1329) By reason of a partial vacuum, a column of water 15 feet in height is supported; what is the tension of the confined air in pounds per square inch?

Ans. 8.246 lb. per sq. in.

(1330) What are the advantages to be derived from using compressed air in mining operations?

(1331) Why should cold free air be used for compression?

(1332) Suppose that air was compressed adiabatically and used immediately, expanding adiabatically back to the original pressure. Would there be any loss due to adiabatic instead of isothermal compression in this case? Why?

(1333) (*a*) What is a *wet* air-compressor? (*b*) What are its advantages and disadvantages?

(1334) Describe the duplex air-compressor, and explain how the arrangement affects the distribution of power between the two compressors.

(1335) Describe the compound air-compressor, and show wherein lies its advantage over the single-cylinder compressor.

(1336) Describe a device for preventing the moisture in the exhaust-air of a compressed-air engine from freezing.

(1337) (*a*) What is an adiabatic curve? (*b*) Which requires the more work, adiabatic compression or isothermal compression, other conditions being the same?

(1338) The temperature of the discharged air of an air-compressor, the tension of which is 40 pounds per square inch, is 120°; when it has cooled down to the temperature of the surrounding air, which is 55°, what is its tension?

Ans. 35.51 lb.

(1339) The stroke and diameter of the piston of a blowing-engine (one form of an air-compressor) are each 80 inches. The valves are so set that they will open for discharge when the tension of the compressed air becomes 9 pounds above the atmosphere. (*a*) At what point of the stroke will the valves open? (*b*) How many cubic feet of air having this tension will be discharged during one stroke of the piston, the temperature being constant throughout?

Ans. { (*a*) 30.38 in.
(*b*) 144.34 cu. ft.

(1340) What should be the size of the steam-cylinder of an air-compressor required to furnish sufficient power to drive a 25-horsepower plant? Assume the boiler-pressure to be 92 pounds, the cut-off to be $\frac{5}{8}$, the ratio of the stroke to the cylinder diameter to be $1\frac{3}{8}$, the number of strokes 340 per minute, and the loss of power 35%.

Ans. $8\frac{3}{8}$ in. × $11\frac{1}{2}$ in., nearly.

(1341) If indicator-diagrams are taken at the same time from the steam-cylinder and the air-cylinder of a compressor, which will show the greater indicated horsepower? How can you account for the difference between the horsepowers shown by the diagrams?

(1342) Describe the electric reheater.

(1343) The diameter and stroke of the piston of an air-compressor are 20 inches and 32 inches respectively. If the discharge-valve opens when the piston has completed 2

inches of its stroke, (*a*) what is the volume of the contained air? (*b*) the weight of the air? The temperature remains at 76° throughout.

Ans. $\begin{cases} (a)\ 1{,}884.96 \text{ cu. in.} = 1.0908 \text{ cu. ft.} \\ (b)\ .43143 \text{ lb.} \end{cases}$

(1344) In example 1343, what is the tension of the air discharged? Ans. 78.4 lb. per sq. in.

(1345) A closed vessel fitted with a piston contains air under a pressure of three atmospheres. If the piston is so moved that the volume is $2\frac{1}{2}$ times its former volume, what is the tension of the gas in pounds per square inch? The temperature is the same in both cases.

Ans. 17.64 lb. per sq. in.

(1346) A certain quantity of air, under a pressure of $1\frac{1}{2}$ atmospheres and a temperature of 75°, weighs 7.14 pounds; what is its volume? Ans. 64.068 cu. ft.

(1347) A certain quantity of air under a pressure of $3\frac{1}{2}$ atmospheres weighs 13 pounds. After expanding under a constant temperature, the weight of the same quantity is only 2 pounds. What is the tension of the air?

Ans. 7.915 lb. per sq. in.

(1348) The stroke of a piston of an air-compressor is 60 inches. When the piston has traveled 50 inches, what is the tension (the temperature at discharge being 130°) of the enclosed air, assuming that the delivery-valves do not open until this point is reached? The original temperature is 60°. The diameter of the piston is 48 inches. Obtain the weight of the air, and then calculate the tension.

Ans. 100.096 lb. per. sq. in.

(1349) A pound of air has a temperature of 127° and a tension of 27 pounds per square inch. What is its volume?

Ans. 8.042 cu. ft.

(1350) The weight of a certain body of air having a tension of 4,000 pounds per square foot and a temperature of 100° is .5 pound. What is its volume?

Ans. 3.728 cu. ft.

(1351) Four cubic feet of air are heated under a constant pressure from 40° to 115°. What is the resulting volume?
Ans. 4.6012 cu. ft.

(1352) State the advantages of cooling air during compression; of reheating it.

(1353) What are the absolute temperatures corresponding to 32°, 212°, 62°, 0°, and −40°?

(1354) Three and one-half pounds of air under a pressure of 10 atmospheres occupy a volume of 4 cubic feet; what is the temperature? Ans. −5.583°.

(1355) State some of the disadvantages of the duplex type of air-compressor.

(1356) 11.798 cubic feet of air are under a pressure of 130 pounds per square inch. If the pressure is lessened until the volume is 75 cubic feet, what is the resulting tension? Ans. 20.45 lb. per sq. in.

(1357) What is the temperature of 14 cubic feet of air having a tension of 18 pounds per square inch and weighing 1.2 pounds? Ans. 107.77°.

(1358) Twenty-one cubic feet of air are heated from 60° to 420°; what is the new volume? Ans. 35.57 cu. ft.

(1359) If 12 cubic feet of air have a temperature of 90° and a tension of 6 atmospheres gauge, what is the weight of 1 cubic foot? Ans. .50586 lb.

(1360) A vessel containing 3 cubic feet of air, weighing .5 pound under a pressure of one atmosphere, has compressed into it enough more of the air to make it weigh 1 pound and 6 ounces; the temperature remaining the same, what is the new tension of the air in pounds per square inch?
Ans. 40.425 lb. per sq. in.

(1361) If 4,516 cubic inches of gas having a temperature of 260° are cooled down to a temperature of 80°, the pressure remaining the same, what is the new volume?
Ans. 1.96 cu. ft.

(1362) If 55 cubic feet of air under a pressure of $1\frac{1}{4}$ atmospheres have a temperature of 88°, what is the weight?
Ans. 4.986 lb.

(1363) Two vessels, the volumes of which are each $7\frac{1}{2}$ cubic feet, are filled with air; the temperature is the same in both, but the pressure in one is two atmospheres, and in the other 40 pounds per square inch. If all of the air in one vessel is compressed into the other, what is the pressure of the mixture after it has cooled down to the original temperature? Ans. 69.4 lb. per sq. in.

(1364) If you are told that the vacuum-gauge of a condenser shows 23 inches vacuum, what do you understand by it? What is the pressure in the condenser?

(1365) What is a pressure of one atmosphere equivalent to in pounds per square foot? Ans. 2,116.8 lb. per sq. ft.

(1366) If the weight of 3 cubic feet of air at a certain temperature and under a pressure of 30 pounds per square inch is .27 pound, what is the weight of one cubic foot under a pressure of 65 pounds per square inch at the same temperature? Ans. 0.195 lb.

(1367) In example 1366, what is the temperature of the air? Ans. 440.64°.

(1368) Two gases, oxygen and nitrogen, are mixed together in a vessel containing 20 cubic feet. The volume and tension of the oxygen are 12 cubic feet and one atmosphere, respectively, and of the nitrogen 8 cubic feet and three atmospheres. The temperature of the two gases and of the mixture remaining the same throughout, what is the tension of the mixture? Ans. 26.46 lb. per sq. in.

(1369) In example 1368, suppose that the volume of the mixture is not known, and that the pressure is required to be 24 pounds per square inch; what is the volume of the mixture? Ans. 22.05 cu. ft.

(1370) What is a vacuum? Illustrate it.

(1371) An air-pump produces a vacuum of $\frac{1}{40}$ of an inch

of mercury; what is the equivalent pressure upon a square foot? Ans. 1.764 lb.

(1372) What is a *partial vacuum?* If enough air is admitted to the vacuum-chamber to cause the column of mercury to be $4\frac{1}{2}$ inches shorter than the barometer column, how many inches of vacuum will the gauge show?

Ans. $25\frac{1}{2}$ in.

(1373) A vacuum of 27 inches will support a column of water of what height? Ans. 30.6 ft.

(1374) What is the purpose of a pressure-regulator? Describe its action.

(1375) What is the office of the receiver? What should be the volume of a receiver which supplies air to 8 rock-drills?

(1376) What is meant by the *efficiency* of an air-compressor? State fully the losses which may occur when compressed air is used. What means should be adopted to reduce these losses as far as possible?

HYDROMECHANICS AND PUMPING.

NOTE.—Pipe diameters are given to the nearest $\frac{1}{4}$ inch; plunger, piston, and cylinder diameters to the nearest $\frac{1}{8}$ inch.

(1377) A weir whose top is 3 feet 6 inches below the surface of the water is 2 feet deep and 30 inches broad; (*a*) what is the actual mean velocity? (*b*) What is the discharge in cubic feet per second? (*c*) in gallons per hour?

Ans. $\begin{cases} (a) \text{ 10.44 ft. per sec.} \\ (b) \text{ 52.21 cu. ft. per sec} \\ (c) \text{ 1,405,910.9 gal. per hour.} \end{cases}$

(1378) A pipe 12,000 feet long and $7\frac{1}{2}$ inches in diameter discharges water under a head of 76 feet; what is the discharge in gallons per minute? Ans. 447.7 gal.

(1379) In the last example, (*a*) what is the velocity of discharge in feet per minute? (*b*) What is the discharge in cu. ft. per second?

Ans. $\begin{cases} (a) \text{ 195.08 ft. per min.} \\ (b) \text{ 1 cu. ft., nearly.} \end{cases}$

(1380) An 8-inch pipe has a hole in it $\frac{1}{2}$ of an inch in diameter; what would be the theoretical velocity of efflux if the surface of the water were 10 feet above the center of the hole? Ans. 25.36 ft. per sec.

(1381) What must be the necessary head in order that a $6\frac{1}{2}$-inch pipe, 1,500 feet long, shall discharge 42,000 gallons of water per hour? Ans. 42.48 ft.

(1382) A vertical cylinder having a diameter of 20 inches and a length inside of 36 inches is filled with water. A pipe having a diameter of $\frac{3}{8}$ of an inch is screwed into the upper head, and fitted with a piston weighing 10 ounces, on which is laid a weight of 25 pounds. If the end of the pipe is 10

feet above the level of the water in the cylinder, (*a*) what is the pressure per sq. in. on the bottom of the cylinder? (*b*) on the top? (*c*) What equivalent weight laid on the lower cylinder-head would replace the pressure it sustains?

Ans. { (*a*) 237.75 lb. (*b*) 236.45 lb. (*c*) 74,692.17 lb.

(1383) If, in Question 1382, a hole one inch in diameter is drilled through the cylinder-wall in the middle of its length, and is covered by a flat plate in such a manner that the water can not leak out, what is the pressure against the plate? Ans. 186.22 lb.

(1384) What is the mean velocity of efflux from a straight pipe 4 inches in diameter and 4,000 feet long, under a head of 120 feet? Ans. 5.38 ft. per sec.

(1385) If the length of the pipe in Question 1384 had been 2,000 feet, what would the velocity of discharge have been in feet per second? Ans. 7.79 ft. per sec.

(1386) A 10-inch pipe 5,280 feet long is required to deliver water with a velocity of 8 feet per second; (*a*) what is the necessary head? (*b*) What is the discharge in gallons per hour?

Ans. { (*a*) 130.73 ft. (*b*) 117,504 gal. per hour.

(1387) What is the actual velocity of discharge from a small square-edged orifice in the side of a vessel, if the water at the center of the orifice has a pressure of 30 pounds per square inch? Ans. 65.34 ft. per sec.

(1388) The upper base of a cylinder submerged in water is 40 feet below the surface. The diameter of the cylinder is 20 inches, the altitude 36 inches, and the bases are parallel. If the bases are horizontal, (*a*) what is the upward pressure of the water on the cylinder? (*b*) the downward pressure on the top of the cylinder?

Ans. { (*a*) 5,863.26 lb. (*b*) 5,454.19 lb.

(1389) A jet of water issues with a velocity of 33 feet per second; what would be the theoretical head necessary to give it this velocity? Ans. 16.931 ft.

(1390) A weir having a depth of 15 inches and a breadth of 21 inches has its top on a level with the upper surface of the water; (*a*) how many gallons will it discharge per hour? (*b*) What is the actual mean velocity in feet per second?

Ans. { (*a*) 216,551 gal., nearly.
(*b*) 3.676 ft. per sec.

(1391) A 3-inch pipe, 6,000 feet long, is required to deliver water at a velocity of 12 feet per second; what head is necessary? Ans. 1,040.37 ft.

(1392) A 5-inch pipe discharges water with a velocity of 7.2 feet per second; how many gallons will it discharge in one day? Ans. 634,478 gal.

(1393) A 5½-inch pipe discharges 38,000 gallons of water per hour; what is the mean velocity in feet per second?

Ans. 8.5526 ft. per sec.

(1394) A weir whose top is on a level with the upper surface of the water is 27 inches broad and 36 inches deep; (*a*) what is the actual discharge in cubic feet per second? (*b*) What is the theoretical discharge?

Ans. { (*a*) 38.44 cu. ft.
(*b*) 62.5 cu. ft.

(1395) If the surface of the water in a 6-inch pipe is 45 feet above the discharge-orifice, which is 1½ inches in diameter, (*a*) what will be the theoretical velocity of efflux? (*b*) If the upper surface of the water sustains an additional pressure of 10 pounds per square inch, what will be the velocity of efflux?

Ans. { (*a*) 53.8 ft. per sec.
(*b*) 66.153 ft. per sec.

(1396) What is the discharge in gallons per second from a 6-inch pipe, if the mean velocity is 7.5 feet per second?

Ans. 11.016 gal.

(1397) What is the actual velocity of discharge through a short tube whose length is twice the diameter of the orifice, if the pressure of the water at the point of discharge is 41 pounds per square inch? Ans. 76.39 ft. per sec.

(1398) A 4-inch pipe discharges 12,000 gallons per hour; what is the mean velocity of discharge in feet per second?

Ans. 5.106 ft. per sec.

(1399) The cylinder of a hydraulic press is 10 inches in diameter. The plunger is forced outwards by means of a small pump which supplies the press-cylinder with water, its piston being $\frac{1}{2}$ inch in diameter and stroke $1\frac{1}{2}$ inches. If a force of 100 pounds is applied to the pump-piston, (*a*) how great a force can it exert on the plunger? (*b*) How far does the plunger advance for one stroke of the piston?

Ans. { (*a*) 40,000 lb. (*b*) .00375 in.

(1400) How many gallons per minute will a weir 14 inches by 20 inches discharge, if the top of the weir is 9 feet below the upper surface of the liquid, (*a*) when the long side is vertical? (*b*) when the short side is vertical?

Ans. { (*a*) 13,491.22 gal. (*b*) 13,322.47 gal.

(1401) What is the mean velocity for both cases of Question 1400?

Ans. { (*a*) 15.46 ft. per sec. (*b*) 15.264 ft. per sec.

(1402) What is the theoretical mean velocity of discharge through a weir whose depth is 3 feet and whose top is level with the upper surface of the water? Ans. 9.26 ft. per sec.

(1403) The surface of the water contained in a vessel is 19 feet above the ground; (*a*) what is the range of the water issuing from an orifice 4 feet 9 inches from the top? (*b*) How far below the surface is the other point of equal range? (*c*) What is the greatest range?

Ans. { (*a*) 16.454 ft. (*c*) 19 ft.

(1404) A 5-inch pipe 1,300 feet long discharges water under a head of 25 feet; what is the number of gallons discharged per hour? Ans. 17,368.95 gal.

(1405) What values of f would you use for $v_m = 2.37$, 3.19, 5.8, 7.4, 9.83, and 11.5, respectively?

(1406) What would be the total pressure on a cube, one

edge of which measures 10½ inches, if sunk 3½ miles below sea-level?

(1407) The diameter of the bottom of a pail is 8 inches, and the height of the contained water is 12 inches; (*a*) what is the total pressure on the bottom of the pail? (*b*) What is the pressure per square inch?

Ans. { (*a*) 21.82 lb.
(*b*) .434 lb. per sq. in.

(1408) What must be the diameter of a pump-plunger to throw 8,000 gallons per hour, the length of the stroke being 10 feet, and the number of strokes per minute 7? Ans. 7⅝ in.

(1409) What are the advantages of the pulsometer?

(1410) If a suction-pump lifts water 25.5 feet near the sea-level, where the height of the mercury column is 30 inches, how high will the same pump lift water on the top of a mountain, where the mercury stands at 22 inches?

Ans. 18.7 ft.

(1411) A dam is 40 feet long and 12 feet high; what is the total pressure on the dam? Assume that a cubic foot of water weighs 62½ pounds. Ans. 180,000 lb.

(1412) Calculate the diameters of the plunger, of the suction-pipe, and of the delivery-pipe for a double-acting pump throwing 750 gallons per minute. Assume 100 feet per minute as piston speed.

Ans. { Plunger, 15 in.
Delivery, 7 in.
Suction, 10 in.

(1413) The total length of a siphon is 840 feet, the head is 40 feet, and the diameter 6 inches; what is the discharge in gallons per hour? Ans. 44,553.6 gal. per hr.

(1414) The lever of a hydraulic press is 7½ feet long, the piston-rod being 1 foot from the fulcrum. The area of the tube is ½ a square inch; that of the cylinder 80 square inches. What weight may be raised by a force of 80 pounds applied at the end of the lever? Ans. 96,000 lb.

(1415) A duplex electric sinking-pump lifts 200 gallons

per minute to a height of 250 feet. The piston speed is 150 feet per min.

(*a*) What should be the diameter of the plunger?
(*b*) What should be the diameter of the suction-pipe?
(*c*) What should be the diameter of the delivery-pipe?
(*d*) What should be the H. P. of the motor?

Ans. { (*a*) $4\frac{1}{2}$ in. (*b*) 5 in. (*c*) $3\frac{1}{2}$ in. (*d*) 19 H. P.

(1416) A hydrant is 210 feet below the surface of the water-supply; (*a*) what is the pressure of the water issuing from the hydrant, and (*b*) what is the theoretical velocity?

Ans. { (*a*) 91.14 lb. per sq. in. (*b*) 116.22 ft per sec.

(1417) Calculate the size of the steam and water cylinders of a duplex direct-acting steam-pump to lift 27,000 gallons per hour to a height of 240 feet. Assume the steam-pressure as 85 pounds per square inch and piston speed as 90 feet per minute.

Ans. { Diameter of steam-cylinder, $10\frac{5}{8}$ in. Diameter of plunger, $8\frac{3}{4}$ in.

(1418) A water-works stand-pipe is filled with water to the height of 70 feet; (*a*) what is the lateral pressure per square inch at the lowest point of the stand-pipe? (*b*) at a distance of 30 feet from the top of the water?

Ans. { (*a*) 30.38 lb. per sq. in. (*b*) 13.02 lb. per sq. in.

(1419) Why are air-chambers used on pumps?

(1420) The diameters of the steam-cylinders of a duplex direct-acting pump are 22 inches. The diameters of the water-cylinders are 14 inches. The steam-pressure is 45 pounds and the piston speed 100 feet per minute; (*a*) how many gallons per hour will this pump raise, and (*b*) to what height?

Ans. { (*a*) 76,769.28 gal. per hr. (*b*) 213.22 ft.

(1421) The plunger of a Cornish pump is 307 feet below the mouth of the discharge-pipe; what is the pressure per square inch on the plunger-cylinder when discharging water at the surface? Ans. 133.238 lb. per sq. in.

(1422) Why must the pit-work of surface engines be balanced? Explain fully.

(1423) Water flows through a 2½-inch pipe, 2,000 feet long, with a velocity of 3.3 feet per second; what is the head? Ans. 39.12 ft.

(1424) (*a*) What horsepower is required to raise 80,000 gallons per hour to a height of 420 feet? (*b*) What should be the horsepower of the pumping-engine to accomplish this?

Ans. { (*a*) 141.87 H. P.
(*b*) 212.8 H. P.

(1425) A pump lifts 30,000 gallons of water per hour to a height of 290 feet; 600 pounds of coal per hour are burned; what is the duty? Ans. 12,114,750 ft.-lb.

(1426) A 6-inch pipe, 6,500 feet in length, has a head of 220 feet; what is the mean velocity of efflux?

Ans. 7.17 ft. per sec.

(1427) What head of water corresponds (*a*) to a pressure of 45 pounds per square inch? (*b*) to 86 pounds per square inch? (*c*) to 108 pounds per square inch?

Ans. { (*a*) 103.68 ft.
(*b*) 198.144 ft.
(*c*) 248.832 ft.

(1428) The diameter of the water-cylinder of a direct-acting pump is 15 inches, and the height of lift is 310 feet; (*a*) what is the diameter of the steam-cylinder? (*b*) What will be the delivery at a piston speed of 100 feet per minute? Take the steam-pressure as 50 pounds per square inch.

Ans. { (*a*) 27 in.
(*b*) 734.4 gal. per min.

(1429) With what velocity, theoretically, will water flow from an orifice 13.7 feet below the surface?

Ans. 29.685 ft. per sec.

(1430) In Fig. 736 the weight on piston *a* is 22 pounds; the area of *a* is 5 square inches, and the area of *b* is 73 square inches; what must be the weight on *b* to just balance the weight on *a*? Ans. 321.2 lb.

(1431) Why can water be sucked up through a straw?

(1432) The diameter of the water-cylinder of a single direct-acting pump is 11 inches. The steam-pressure is 50 pounds per square inch, and the height of the lift is 300 feet; (*a*) find the discharge per hour. (*b*) Find the diameter of the steam-piston. (*c*) What is the horsepower of the pump? Assume the piston speed as 100 feet per minute.

Ans. { (*a*) 23,696.64 gal. per hr.
(*b*) 19½ in.
(*c*) 45.024 H. P.

(1433) If a piece of glass be laid upon a flat surface which has been moistened, it will require considerable exertion to separate them. Why?

(1434) The total length of a siphon is 88 feet; the head is 15 feet, and the diameter 3½ inches; what is the discharge in gallons per minute? Ans. 342.66 gal. per min.

(1435) What should be the size and proportions of a direct-acting steam-pump to deliver 18,000 gallons per hour against a head of 225 feet? Assume the average steam-pressure to be 50 pounds per square inch. Add one-half to the indicated horsepower for friction, etc., and take the piston speed as 110 feet per minute.

Ans. { Diameter of steam-cylinder, 14 in.
Diameter of water-cylinder, 9⅛ in.
Stroke, 12 in.
Diameter of suction-pipe, 6 in.
Diameter of discharge-pipe, 4½ in.

(1436) The area of the cross-section of an orifice in a thin plate is 11.2 square inches. There being a constant head of 15 feet 9 inches, (*a*) what is the theoretical discharge

in cubic feet per minute? (*b*) What is the actual discharge in cubic feet per minute?

Ans. { (*a*) 148.54 cu. ft. per min.
(*b*) 91.344 cu. ft. per min.

(1437) Why must a siphon be filled with water, or have the air exhausted from it, before it will work?

(1438) The diameter of the plunger of a pump is 19 inches; the length of the stroke is 9 feet, and the number of strokes per minute 5; (*a*) what is the discharge in gallons per minute? (*b*) per hour? Calculate the discharge by formula **191.**

Ans. { (*a*) 530.24 gal. per min.
(*b*) 31,814.4 gal. per hr.

(1439) A pumping-engine lifts 80,000 gallons per hour 340 feet, with a coal consumption of 400 pounds; what is the duty? Ans. 56,814,000 ft.-lb.

(1440) Find the heads of water corresponding to the following pressures: (*a*) 80 pounds per square inch; (*b*) 30.5 pounds per square inch; (*c*) 108 pounds per square inch; (*d*) 215 pounds per square inch.

Ans. { (*a*) 184.32 ft.
(*b*) 70.272 ft.
(*c*) 248.832 ft.
(*d*) 495.36 ft.

(1441) The piston speed of a duplex steam-pump is 100 feet per minute; the diameter of the plunger is 14 inches; what is the delivery in gallons per hour?

Ans. 76,769.28 gal. per hr.

(1442) A 4-inch pipe 5,000 feet long is required to deliver water with a velocity of 8 feet per second; what must be the head? Ans. 307.46 ft.

(1443) A cylindrical vessel, 3 feet in diameter and 12 feet long, is placed upon one end, so that its axis is vertical. Suppose that it is kept filled with water which flows through a hole in the bottom; what will be the velocity of efflux if the hole is 11 inches square? Ans. 27.979 ft. per sec.

(1444) A compound condensing pumping-engine delivers

4,000,000 gallons of water in 10 hours, against a head of 125 feet. The number of pounds of coal burned in 10 hours is 7,460; what is the duty? Ans. 55,998,660 ft.-lb.

(1445) A Cornish pumping-engine has a stroke of 10 feet. The pit-work weighs 20 tons, the water-column 12 tons, and the frictional resistances are 3 tons; what must be the weight of the counterbalance in order that the greatest speed of the pit-work may be about 200 feet per minute? Ans. 2.6 tons.

(1446) How is the expansion of steam obtained in a compound pumping-engine?

(1447) State some of the advantages of using an electric sinking-pump.

(1448) What should be the diameters of (*a*) the suction and (*b*) delivery pipes of a pump which discharges 70,000 gallons of water per hour? Ans. { (*a*) 12 in. (*b*) $8\frac{1}{2}$ in.

(1449) What must be the horsepower of a pump to deliver 100,000 gallons of water per hour against a head of 480 feet? Ans. 304 H. P.

(1450) How many gallons per hour will a 7-inch pipe deliver, if the mean velocity of the water at the point of efflux is 7.21 feet per second? Ans. 51,891.24 gal. per hr.

(1451) What special advantages does the Cameron sinking-pump possess over other steam sinking-pumps?

(1452) In what cases can a hydraulic pump be used to a great advantage?

(1453) State what is meant by a Cornish pumping-engine; a Bull engine; a sinking-pump; a hydraulic engine; a siphon.

(1454) What is the usual practice in regard to the velocity of the water in the suction-pipe? in the delivery-pipe? What is the usual limit of piston speed in pumps?

(1455) How many gallons of water will a pump deliver

per hour, if the diameter of the pump-cylinder is 15 inches and the piston speed is 95 feet per minute?

Ans. 41,860.8 gal. per hr.

(1456) State what is meant by a compound, a duplex, a single compound, an outside packed triplex, and an outside packed compound condensing duplex pump.

(1457) A jet of water issues from an orifice under a head of 69.12 feet; what is the actual velocity in feet per second?

Ans. 65.34 ft. per sec.

(1458) A squirt-gun has a hole in it $\frac{3}{32}$ of an inch in diameter. It is held vertically upwards, and a pressure of 50 pounds is applied to the piston, which is $\frac{7}{8}$ of an inch in diameter. Neglecting all resistances, (*a*) how high will the water rise? (*b*) If held horizontally 10 feet from the ground, what will be its range?

Ans. { (*a*) 191.6 ft. (*b*) 87.54 ft.